GRAUPEL AND HAIL ALGORITHM for GPM-DPR

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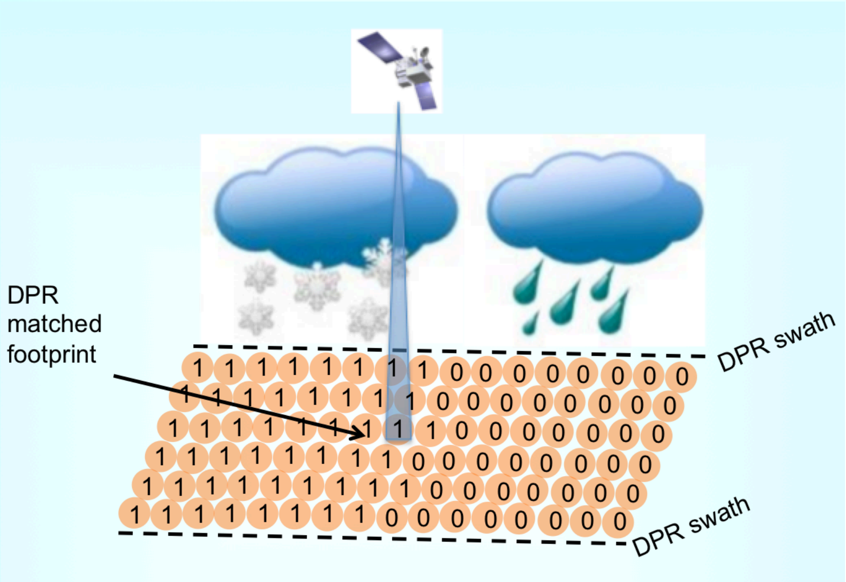
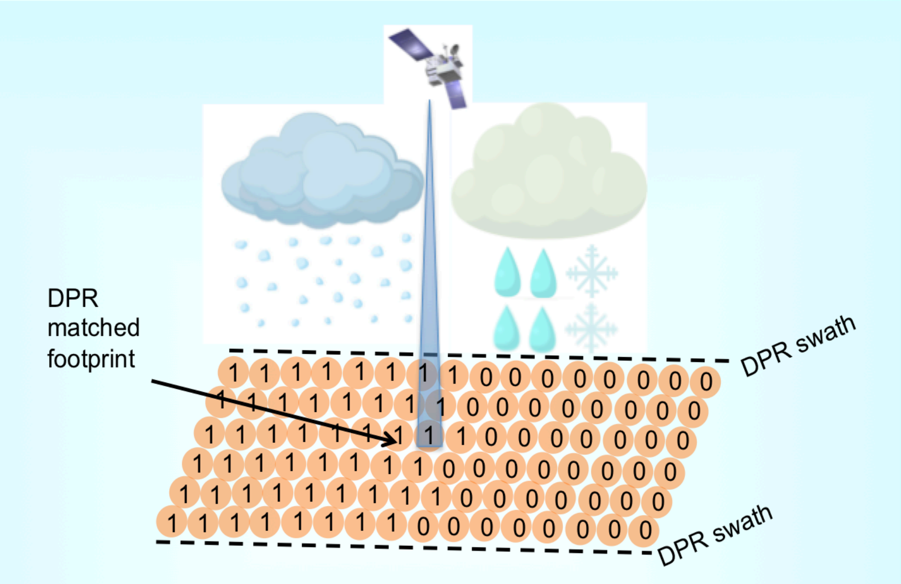
Outline

- Background
- Algorithm Description
- Algorithm Validation Activities
    - Validation with WSR-88D radar network
    - Validation with CSAPR radar during Relampago field campaign
- Global Scale Analysis
- Summary and Conclusion

Background





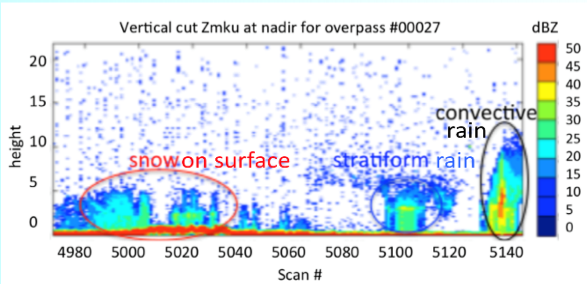
- In the current DPR level-2 algorithm, the “flagSurfaceSnowfall” is a Binary product detects whether surface has snowfall or not (Le and Chandrasekar, 2019).
- A precipitation type index (PTI) with certain threshold is used to identify surface snowfall.
- Same precipitation type index but with different threshold is used to identify graupel and hail (Le and Chandrasekar, 2018).
- The product of “flagGraupelHail” (or “GH flag”) has been implemented in the Experimental structure. Its format is similar to “flagSurfaceSnowfall”. The output is Binary. 1 represents "graupel and hail exists" and 0 means "graupel and hail not exists". This is for along the vertical profile, not for surface.

Background : GH profile features

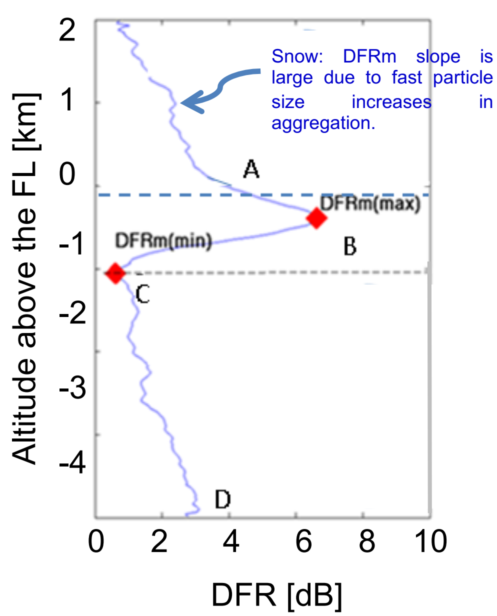
$$\textbf{Precipitation type index (PTI)} = \frac{DFR_m \text{ slope with respect to height}}{\text{Maximum of } Zm_{ku} \cdot \text{Storm top height}}$$

Magnitude of slope and normalized Zmku and storm top height are used in calculating PTI.

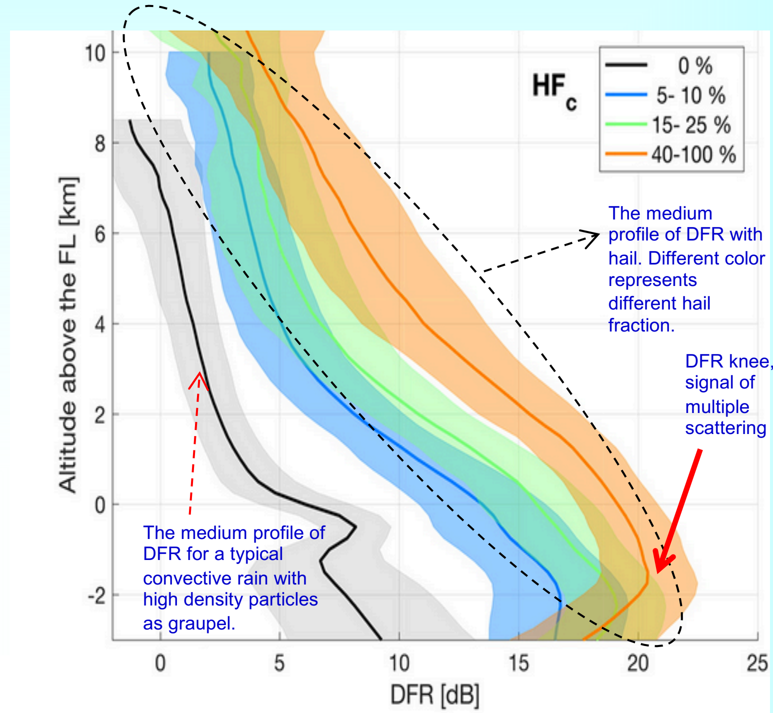
- Large reflectivity and DFRm values can be observed associated with large rimed hail particles and large attenuation.
- The slope of the DFRm is smaller than aggregates. In hail formation, heavily rimed particles lifted up by the updraft, there is no strong indication of one-way size increase or attenuation difference increase.
- High storm top.
- Multiple scattering could happen.



	Stratiform rain	Snow	Graupel & Hail
DFR_m slope with respect to height	small	large	medium
Maximum of Zm_{ku}	small	small	large
Storm top height	small	small	large
PTI index	medium	large	**small**



Typical profile of DFR for stratiform rain with snow particles above freezing level (Le and Chandrasekar, 2013)

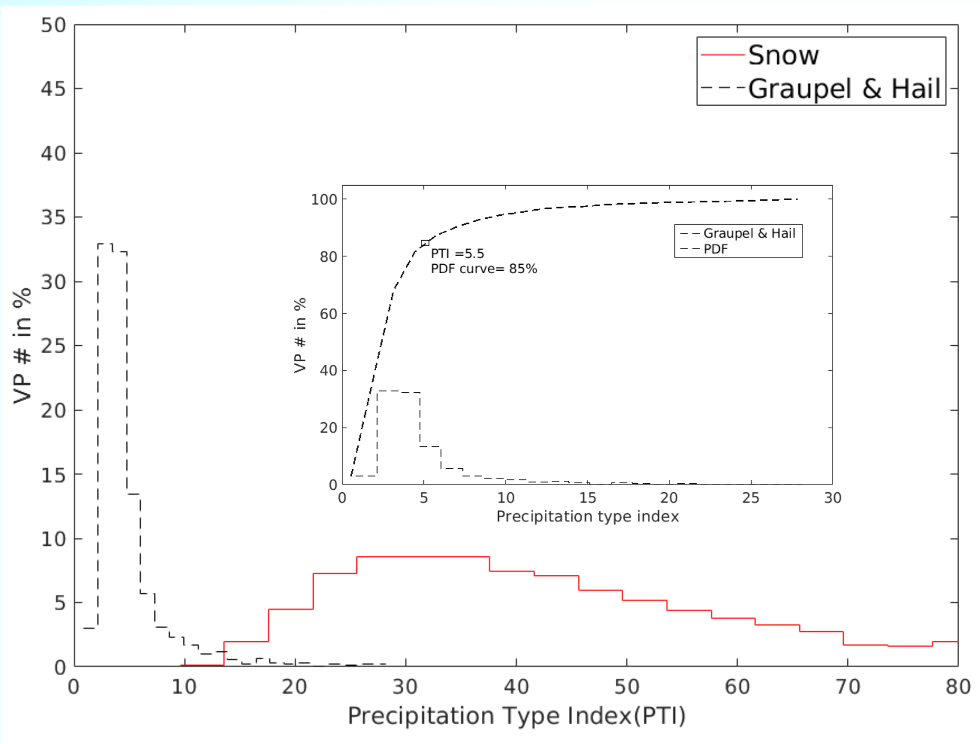


The median profiles of the DFR observables complemented by the synthetic ground-based data for different hail fractions (Mroz et al. 2018). The black line represents hail-free columns, whereas the colored lines are associated with different hail-contamination levels. The semitransparent envelope marks the region between the 25th and 75th percentiles. Hail fraction is judged from the fuzzy logic hydrometeor classification.

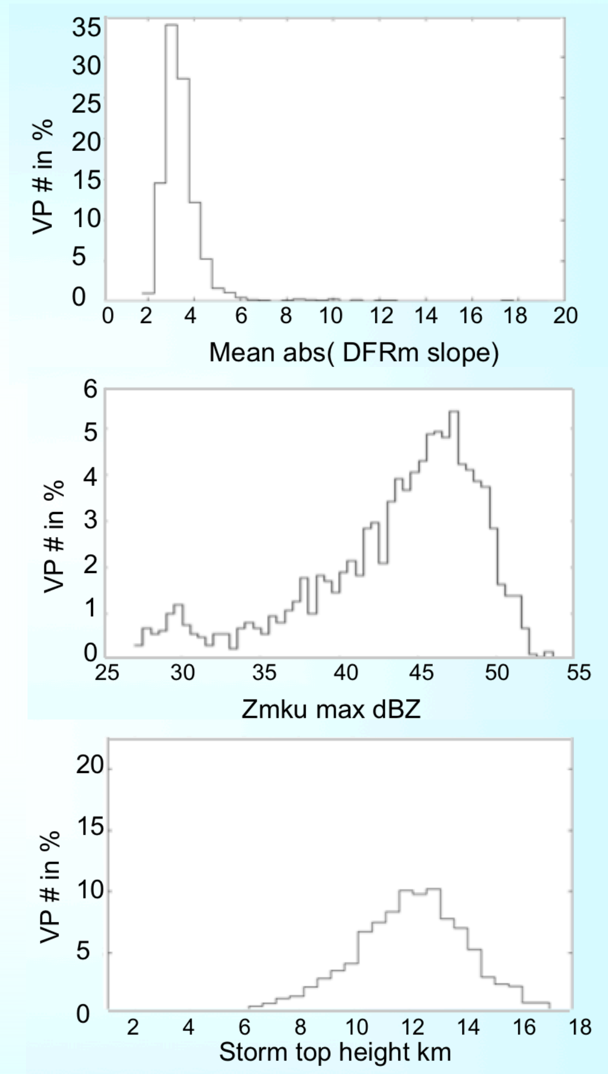
Algorithm: Graupel and Hail detection

- We collect DPR profiles with **graupel and hail** identified using NEXRAD radar network. Hydrometeor classification algorithm (DROPS) is applied to the NEXRAD radar data. We pick DPR vertical profiles closest to the location where DROPS detects graupel and hail. More than 1000 profiles are collected.
- We study features of these dual-frequency profiles. They include maximum of Zmku along vertical profile, mean of absolute of DFRm slope, and storm top height. These three features are used in calculating the precipitation type index.

Precipitation type index for various precipitation



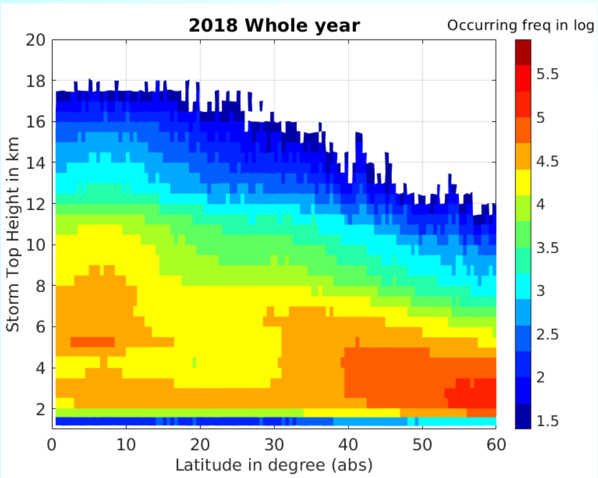
Histogram of features for Graupel and Hail profiles.

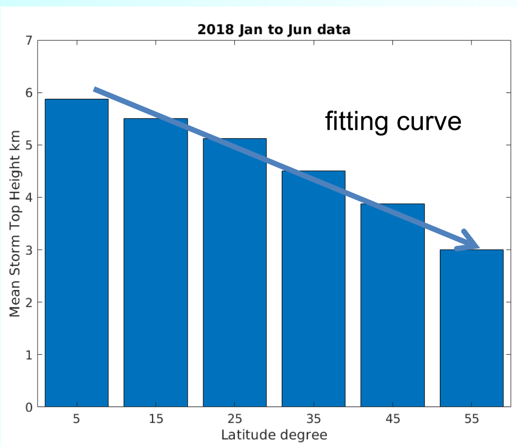


Statistically, around 85% of graupel/hail profiles have this index value smaller than 5.5 and 90% smaller than 6.0. This threshold can be used to identify profiles with graupel and hail.

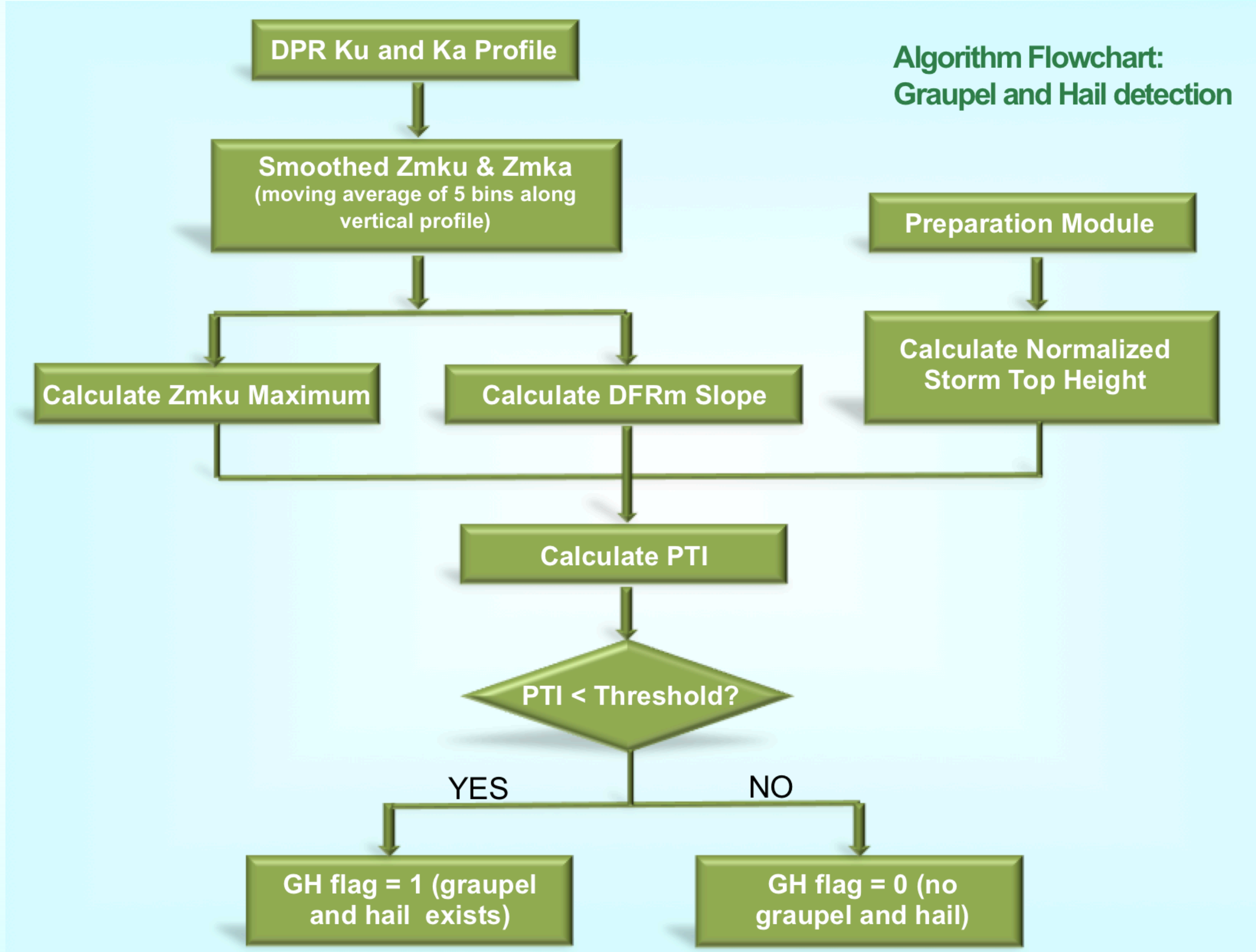
Algorithm: Graupel and Hail detection

Storm Top Height Normalization Due to Latitude



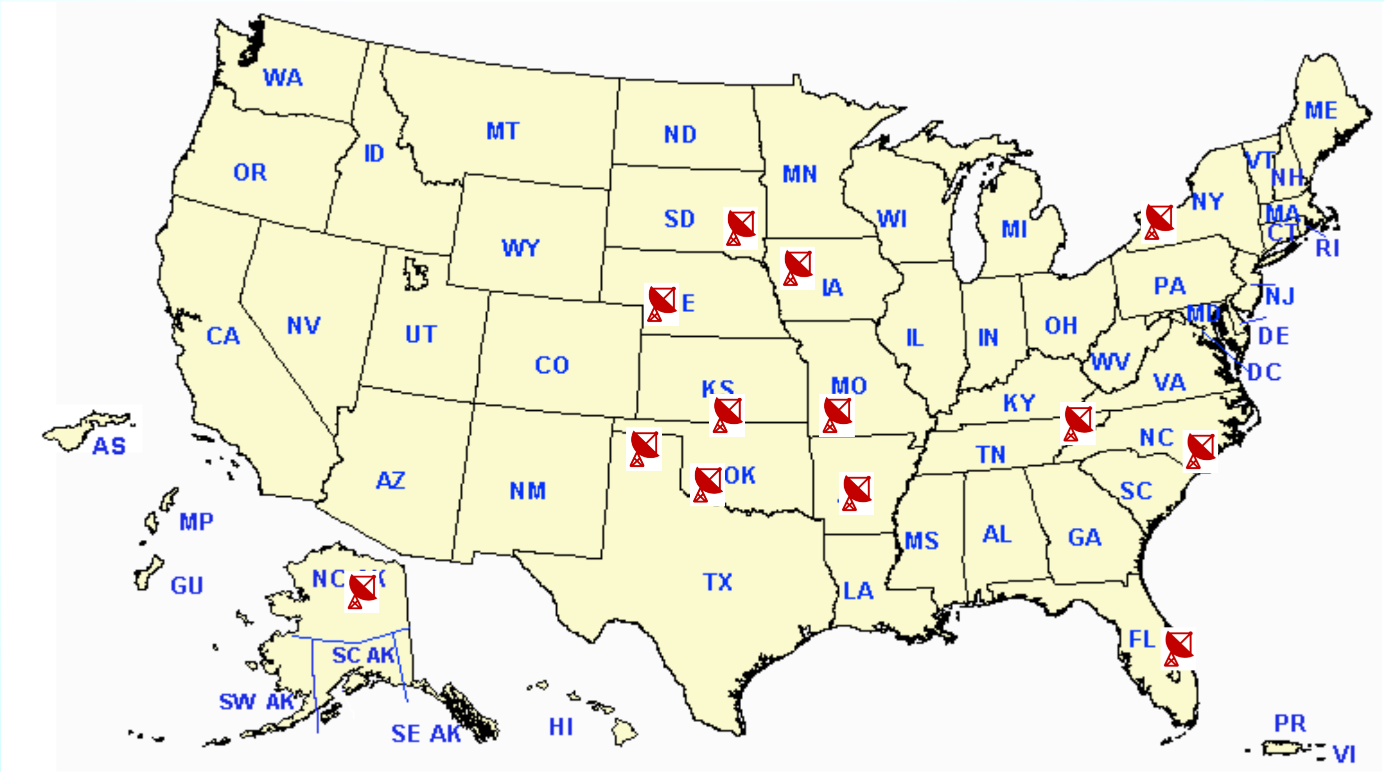


Storm top normalization is introduced to get a smooth transition of Graupel and Hail detection along varying latitude.



Algorithm Validation with WSR-88D radars

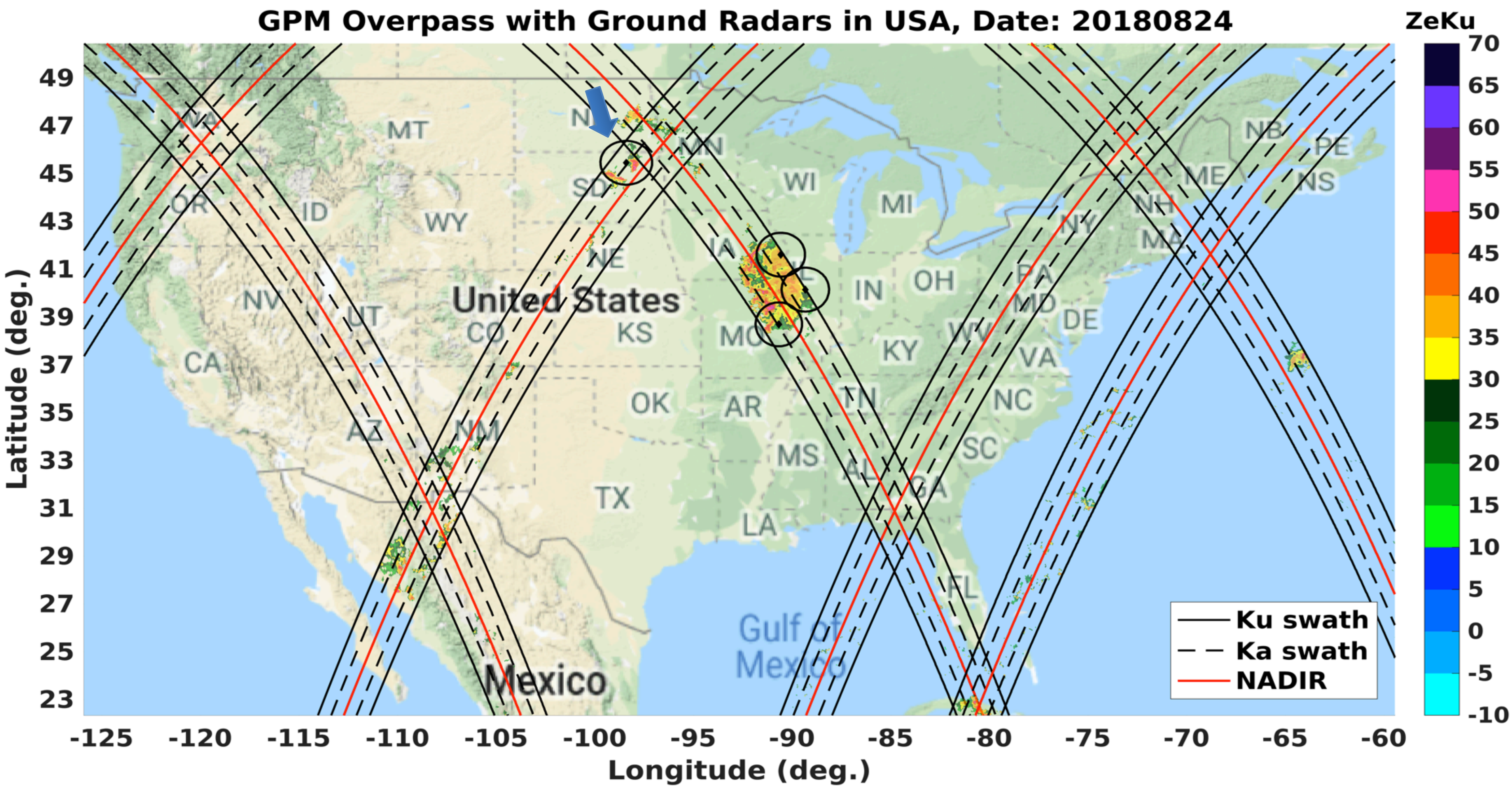
- 13 intense weather events are chosen between 2018 May to 2018 September over United States.
- These precipitation events are simultaneously captured by GPM-DPR and WSR-88D radars. Hydrometeor identification algorithm is performed on WSR-88D radars first. Chosen cases are all detected with Graupel or Hail.
- Graupel and Hail identification algorithm for GPM is applied and the product of “flagGraupelHail” is compared with ground radar results.



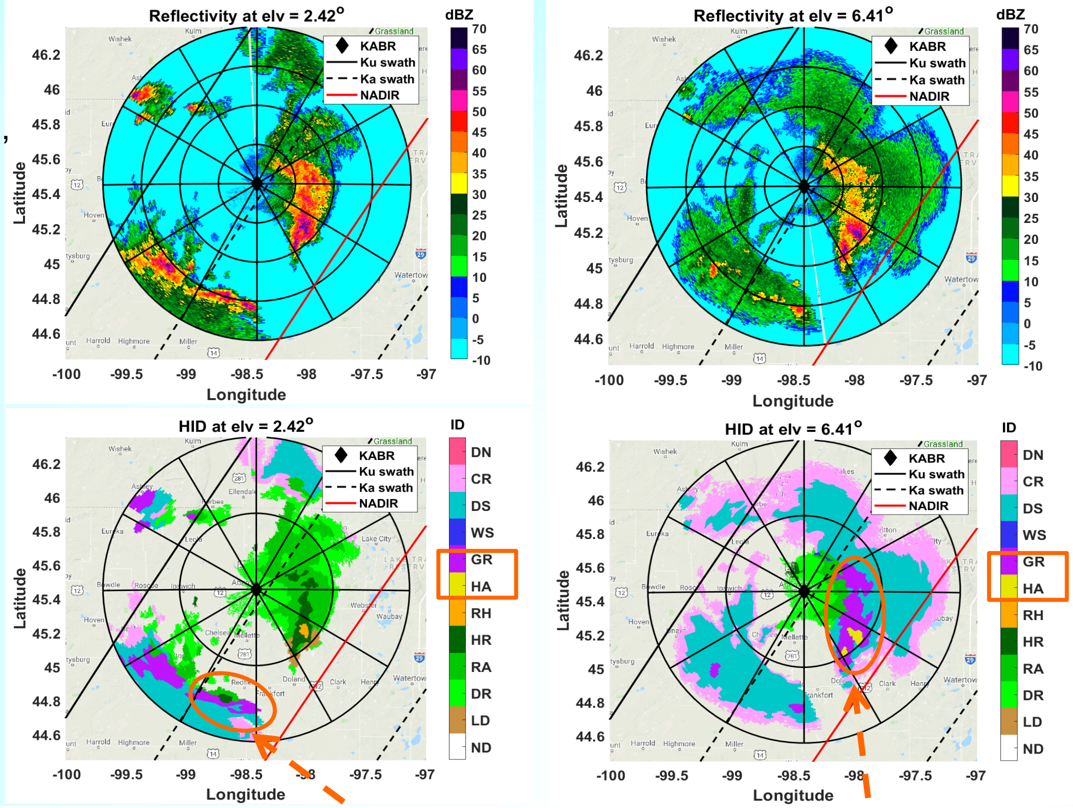
WSR-88D radar locations where we have done validation

Ground Validation with WSR-88D radars

Sample case 1: GPM DPR orbit # 25489 on 2018-08-24 at UTC: 02:42:57
NEXRAD radar: KABR located at Aberdeen, SD at UTC: 02:42:02



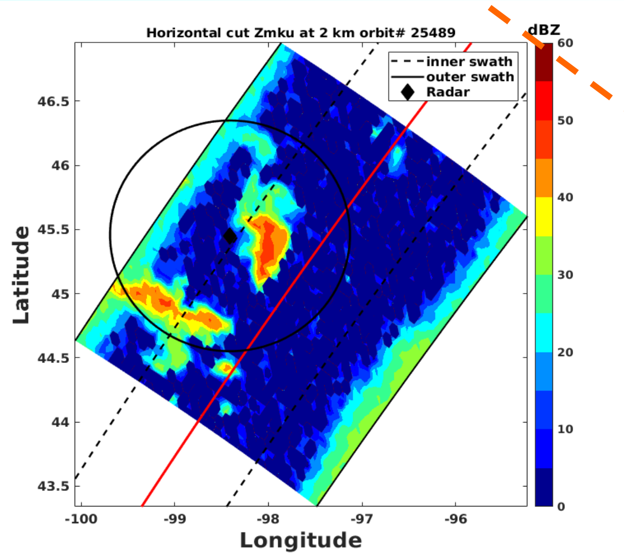
KABR (Aberdeen, SD)

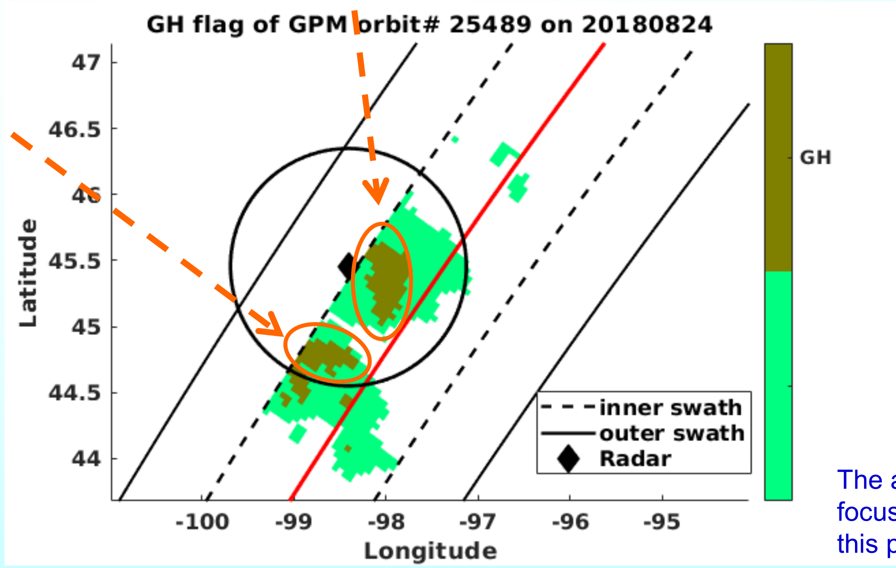


Abbreviation	Type	Abbreviation	Type
DN	Dendrite	RH	Rain and hail
CR	Crystal	HR	Heavy rain
DS	Dry snow	RA	Rain
WS	Wet snow	DR	Drizzle
GR	Graupel	LD	Large drop
HA	Hail	ND	No data

HID algorithm for ground radar is from Bechini and Chandrasekar, 2015

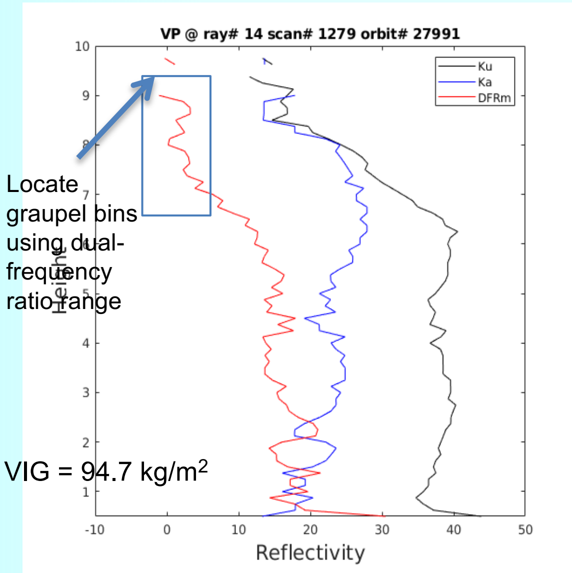
GPM

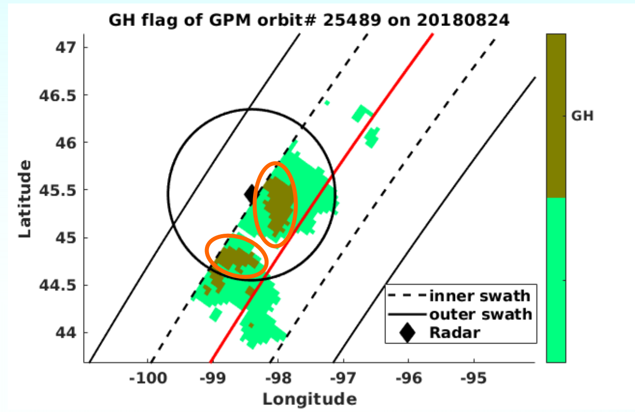


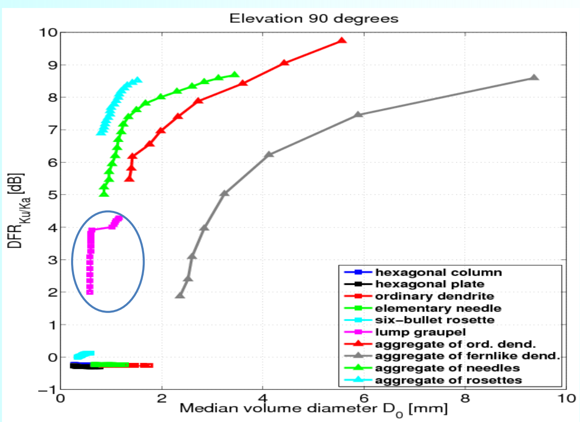


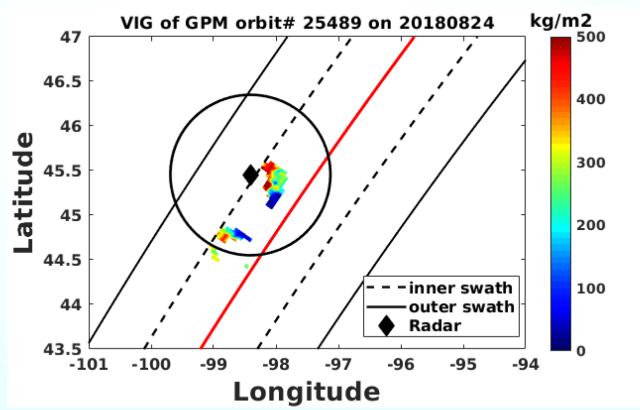
The algorithm evaluation is focused on DPR inner swath in this presentation.

Vertical Integrated Graupel









- N_0 ($= 4 \times 10^6$ m^{-4}) is the intercept parameter of an exponential distribution, unit: m^{-4}

For simplicity, a fixed intercept parameter N_0 is taken from a bulk-microphysical cloud modeling study of tropical convection over the Tiwi Islands (Peterson, 1997).

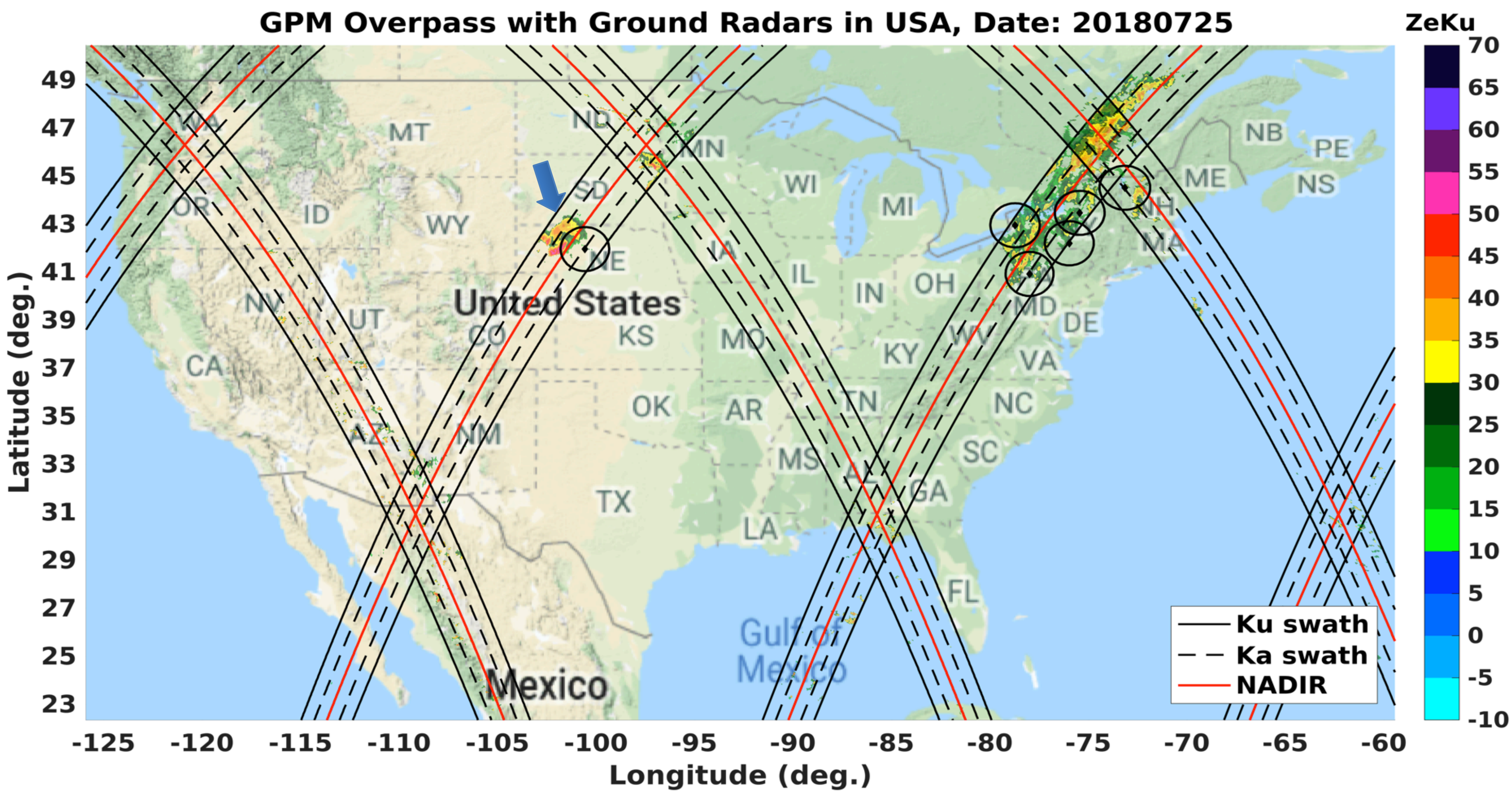
- ρ_g ($= 0.7$) is the Graupel density, unit: kg m^{-3}
- dH is vertical resolution, unit: mm
- Z is reflectivity in unit: mm^{6}m^{-3}

Vertical Integrated Graupel: $\mathrm{VIG} = 1000\pi\rho_g {N_0}^{3/7}(\frac{5.28*10^{-18}}{720})^{4/7} * \int Z^{4/7} dH$ (Kg m^{-2})

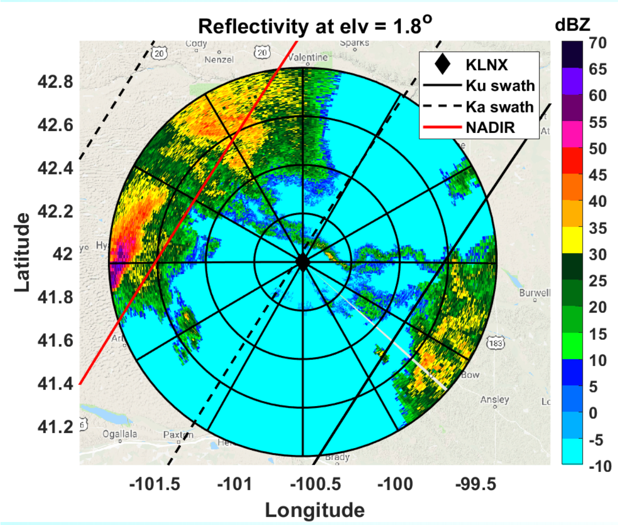
Carey, L.D., and S.A. Rutledge, 2000: The relationship between precipitation and lightning in tropical island convection: A C-Band polarimetric radar study. *Mon. Wea. Rev.*, **128**, 2687–2710.

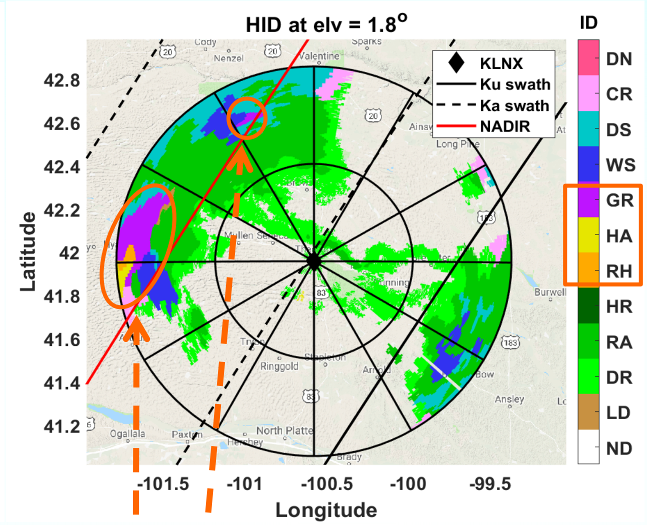
Ground Validation with WSR-88D radars

Sample case 2: GPM DPR orbit # 25028 on 2018-07-25 at UTC 11:25:49
NEXRAD radar: KLNX located at North Platte, NE at UTC: 11:23:35



KLNX (North Platte, NE)





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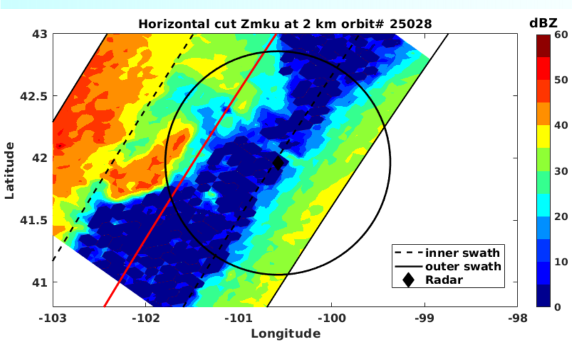
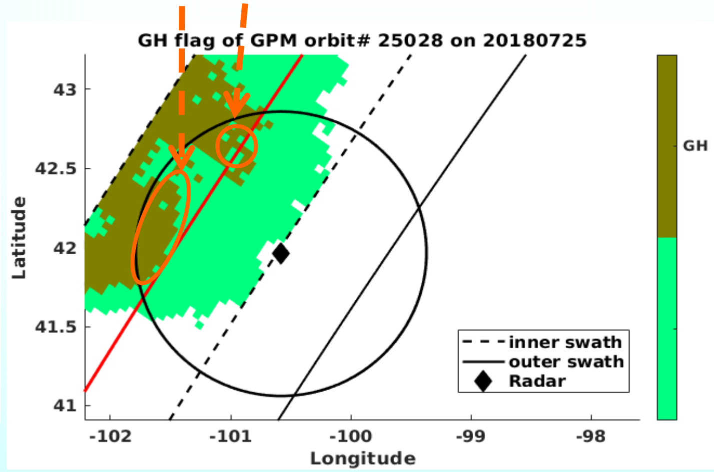
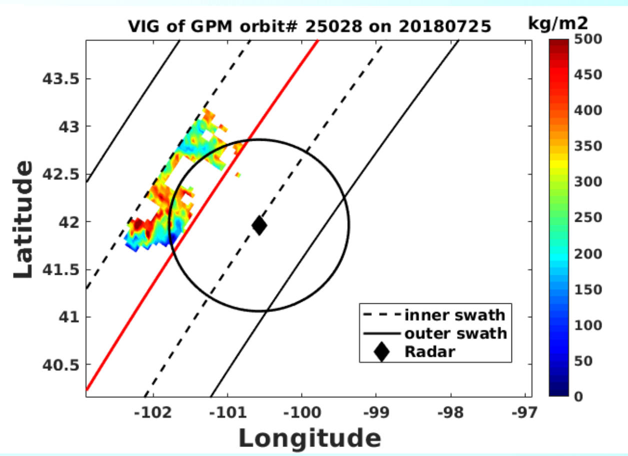
GPM

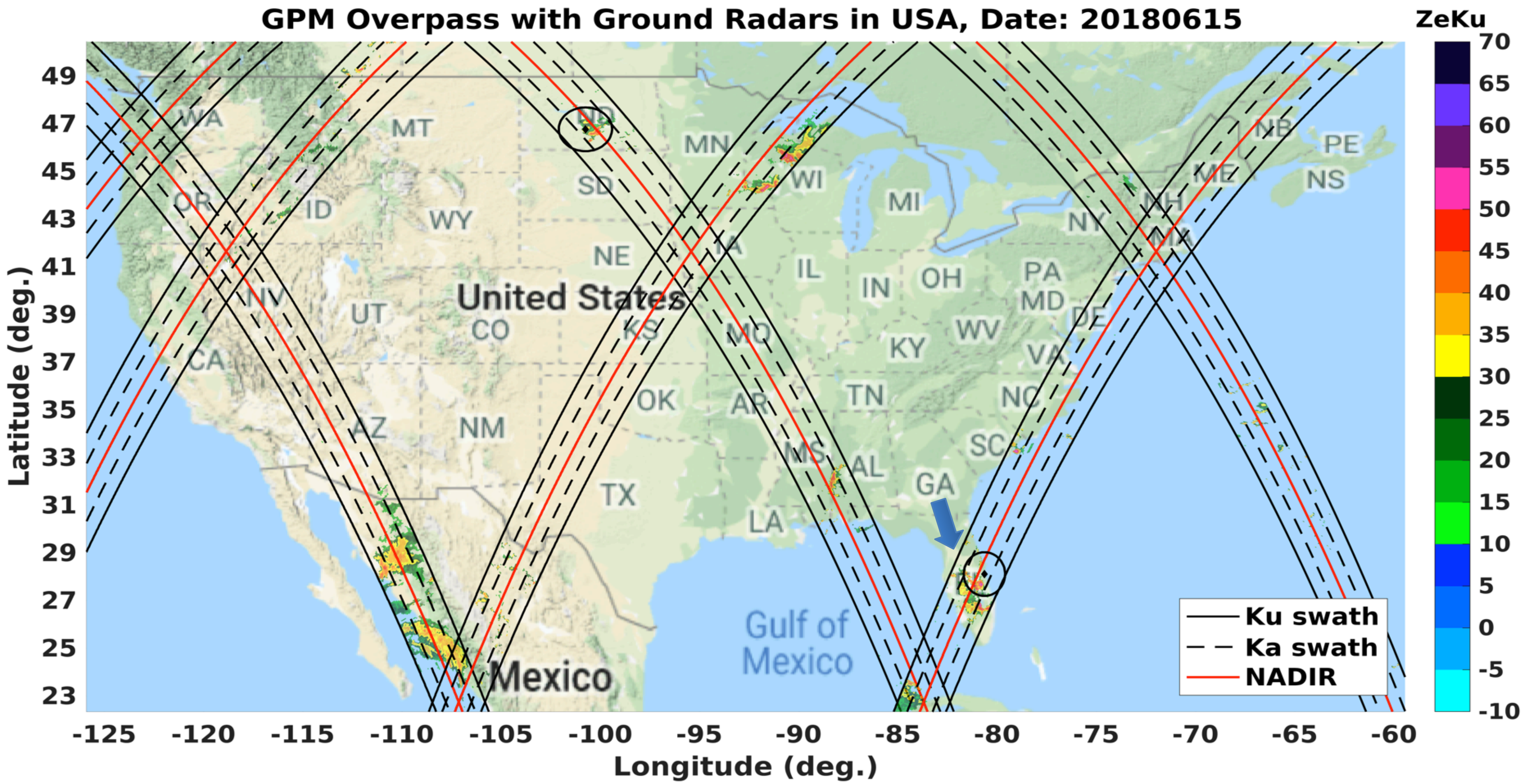






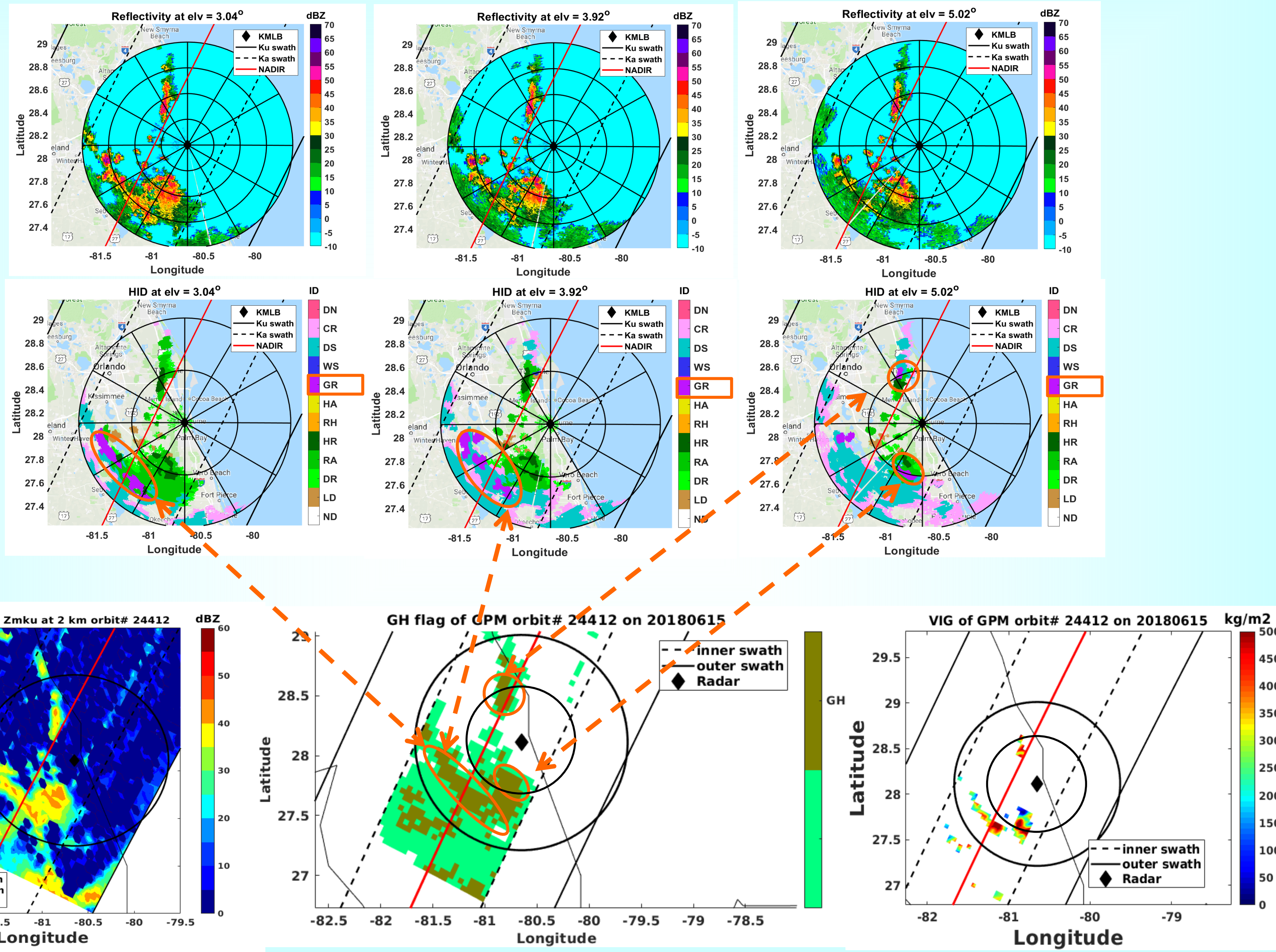
Ground Validation with WSR-88D radars

Sample case 3: GPM DPR orbit # 24412 on 2018-06-15 at UTC 20:57:22
NEXRAD radar: KMLB located at Melbourne, FL at UTC 20:56:08



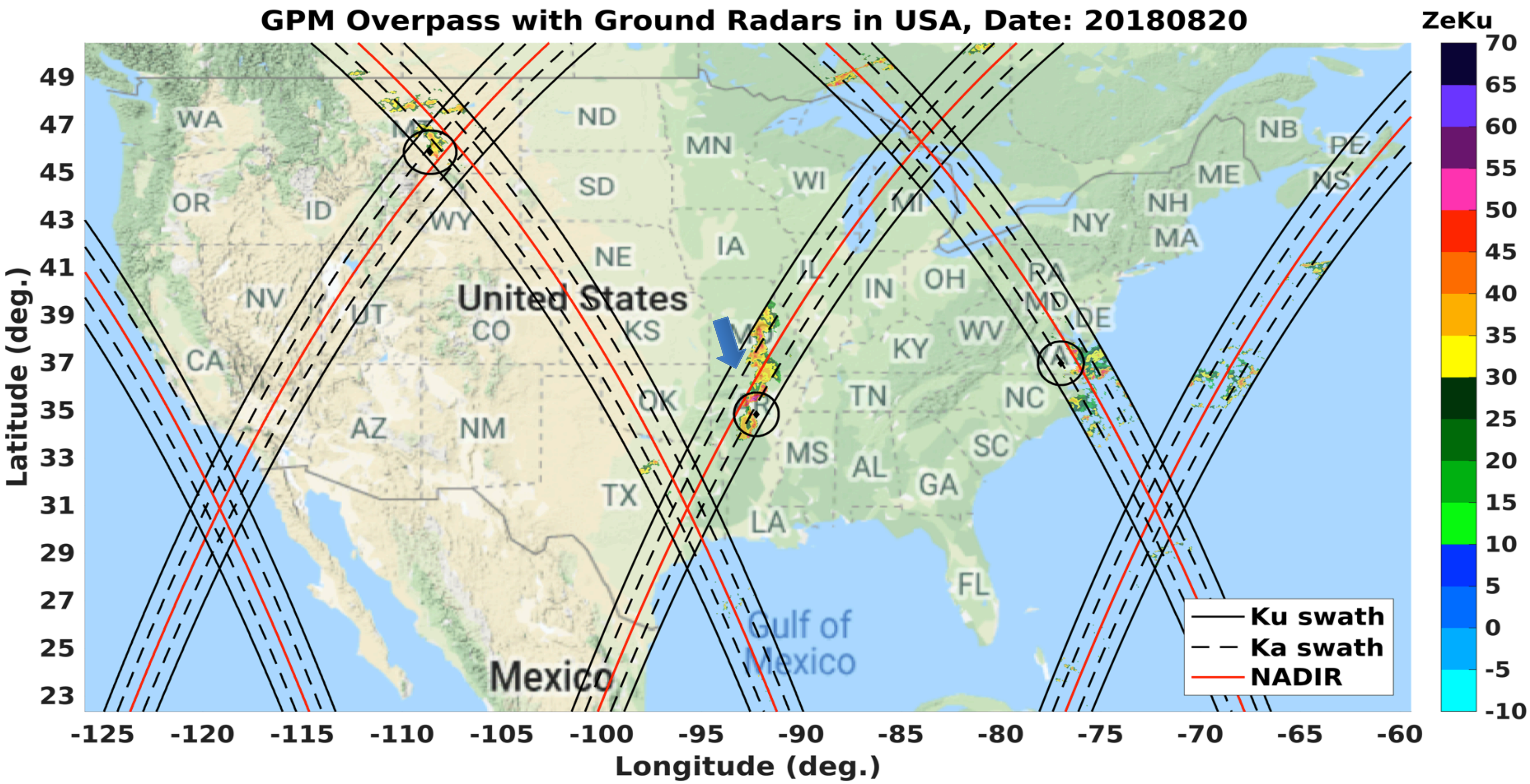
KMLB (Melbourne, FL)

GPM

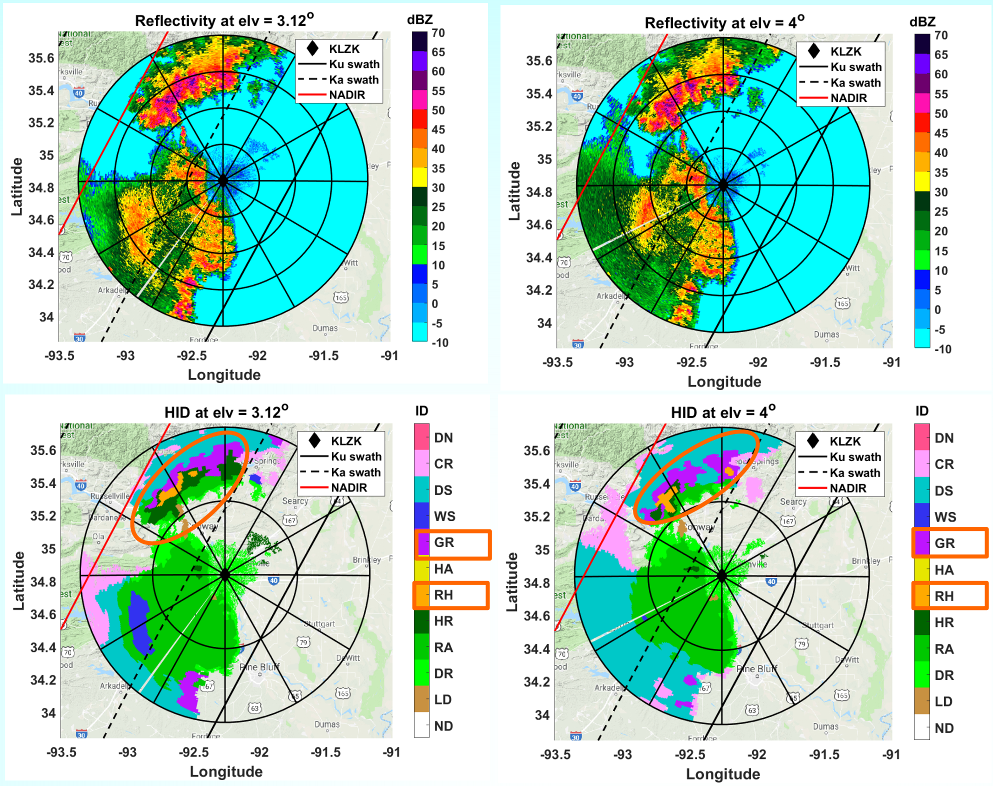


Ground Validation with WSR-88D radars

Sample case 4 : GPM DPR orbit # 25427 on 2018-08-20 at UTC 02:59:43
NEXRAD radar: KLZK located at Little Rock, AR at UTC 03:03:11



KLZK
(Little Rock, AR)



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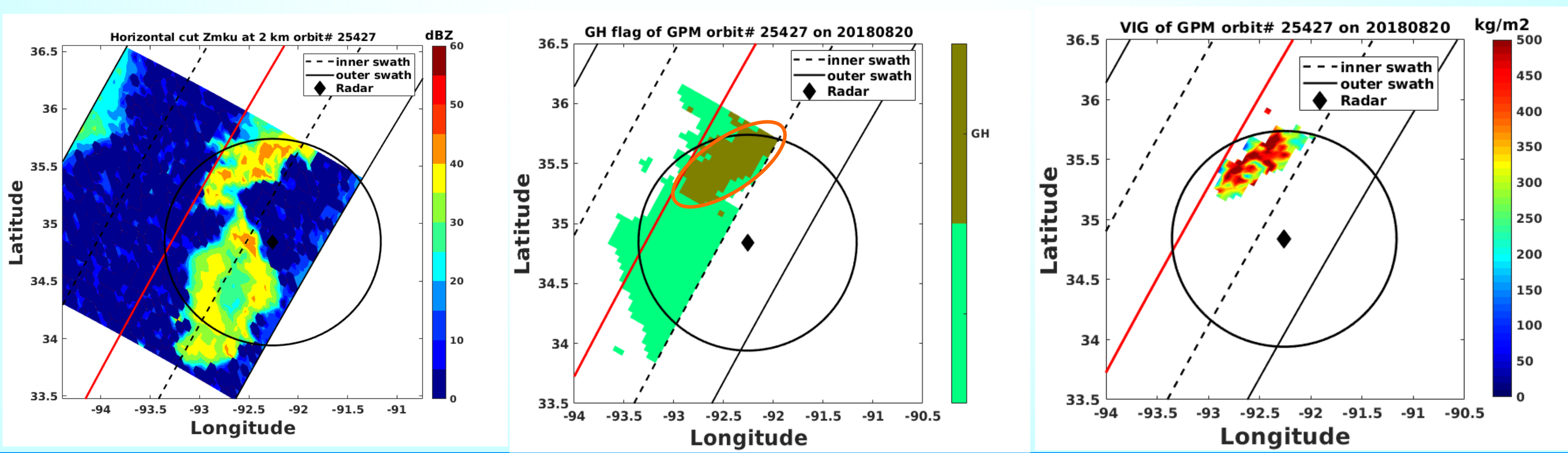
GPM

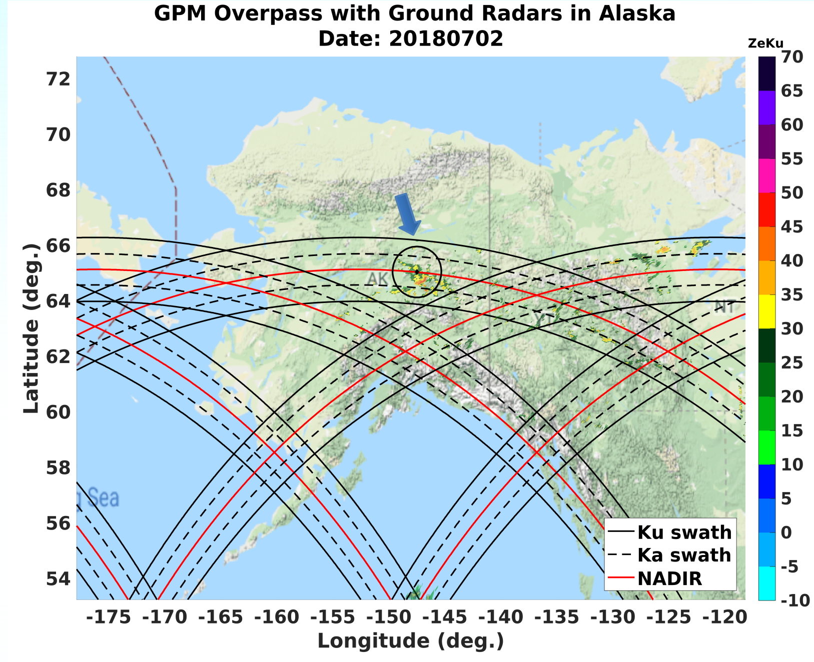


Ground Validation at High Latitude

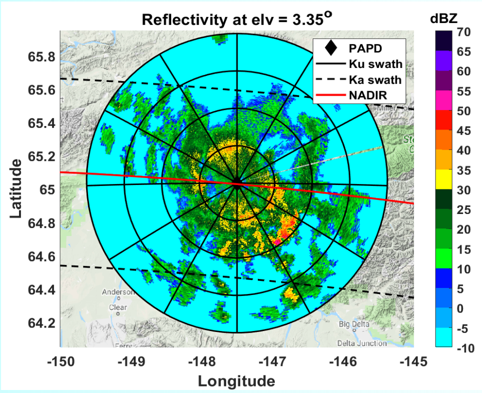
Sample case 5: High Latitude

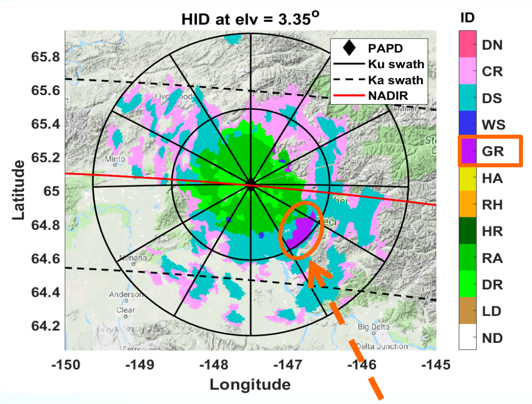
GPM DPR orbit # 24664 on 2018-07-02 at UTC 02:03:33

NEXRAD radar : PAPD located at Fairbanks, AK at UTC 02:03:56

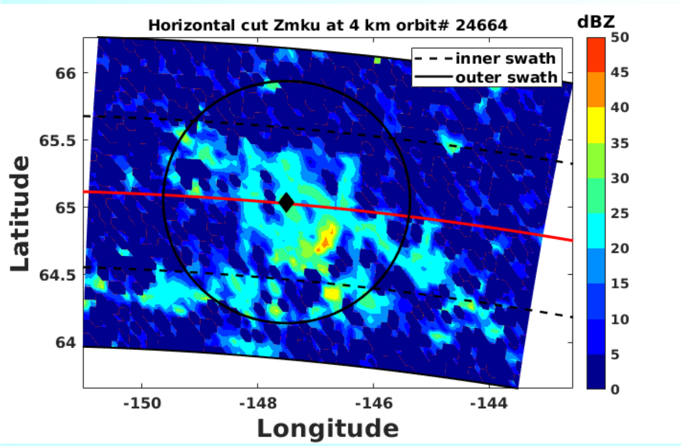


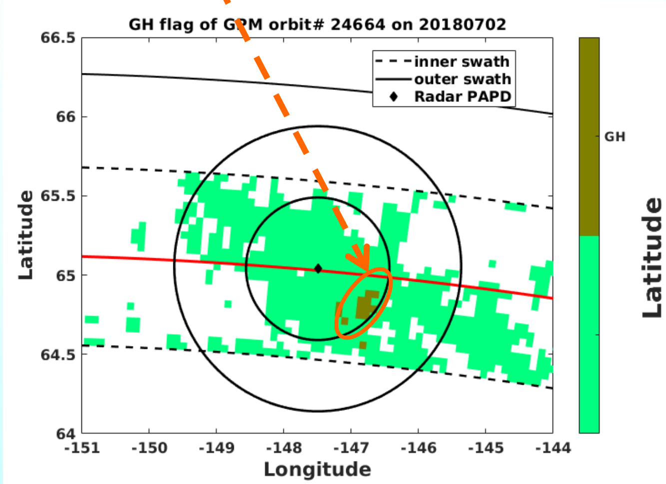
PAPD

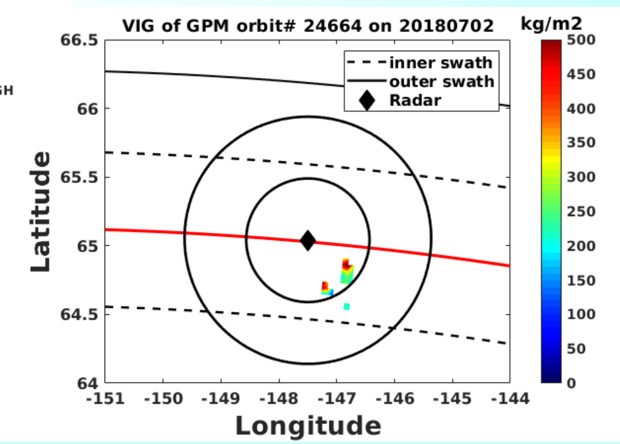




GPM



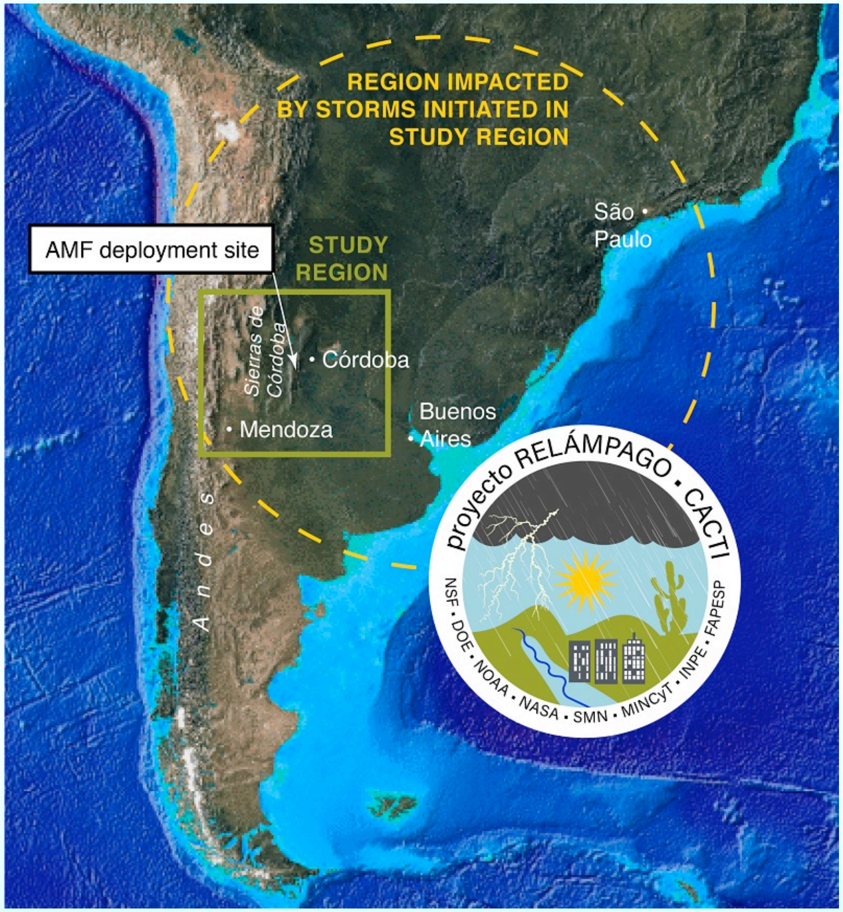




Ground Validation during Relampago field campaign

- **Relampago**
Remote sensing of Electrification, Lightning, And Mesoscale/microscale Processes with Adaptive Ground Observations (translates to lightning flash in Spanish and Portuguese)

- RELAMPAGO is a collaborative project funded by NSF, NOAA, NASA, Servicio Meteorologico Nacional (SMN), Ministry of Education, Science and Technology of Argentina (MinCyT), Province of Cordoba, Brazil (INPE, CNPq, and FAPESP), and INVAP, S.E. to observe convective storms that produce high impact weather in the lee of the Andes mountains in Argentina.



https://www.eol.ucar.edu/field_projects/relampago

- The Intensive Observing Period is between November 2018 to early January 2019.

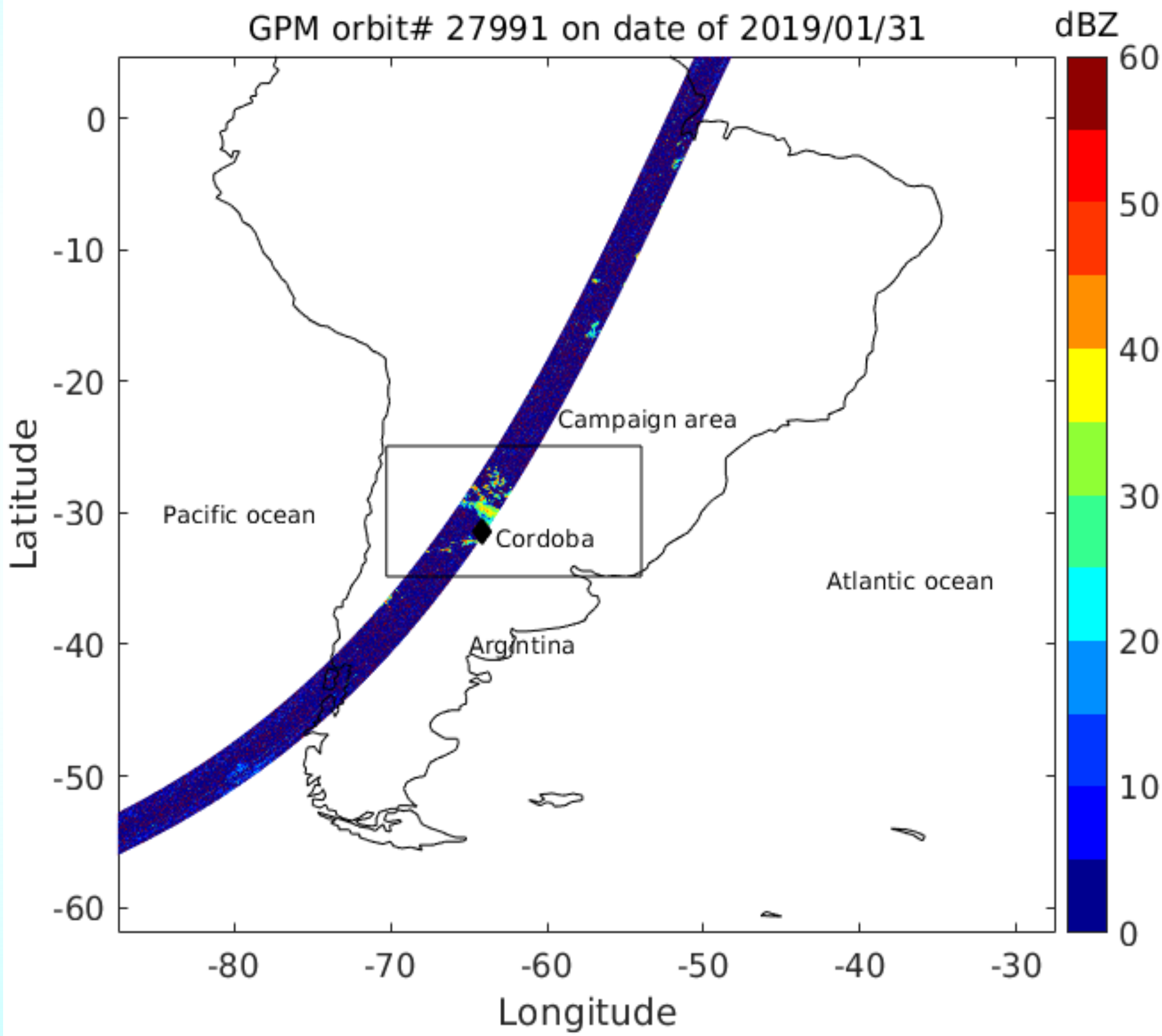
- RELAMPAGO provides unique observations of atmospheric and surface conditions in a region with substantial terrain and explore a regime of convection not observed comprehensively.

- Data for this project were collected using both fixed and mobile instrumentation platforms. These include a research aircraft, mobile mesonets, lightning instruments, weather balloons, fixed and mobile Doppler/dual polarization radars (from W- to C-Band), lidars, microwave profilers, and surface flux measurements.

Validation during Relampago

Case detail:

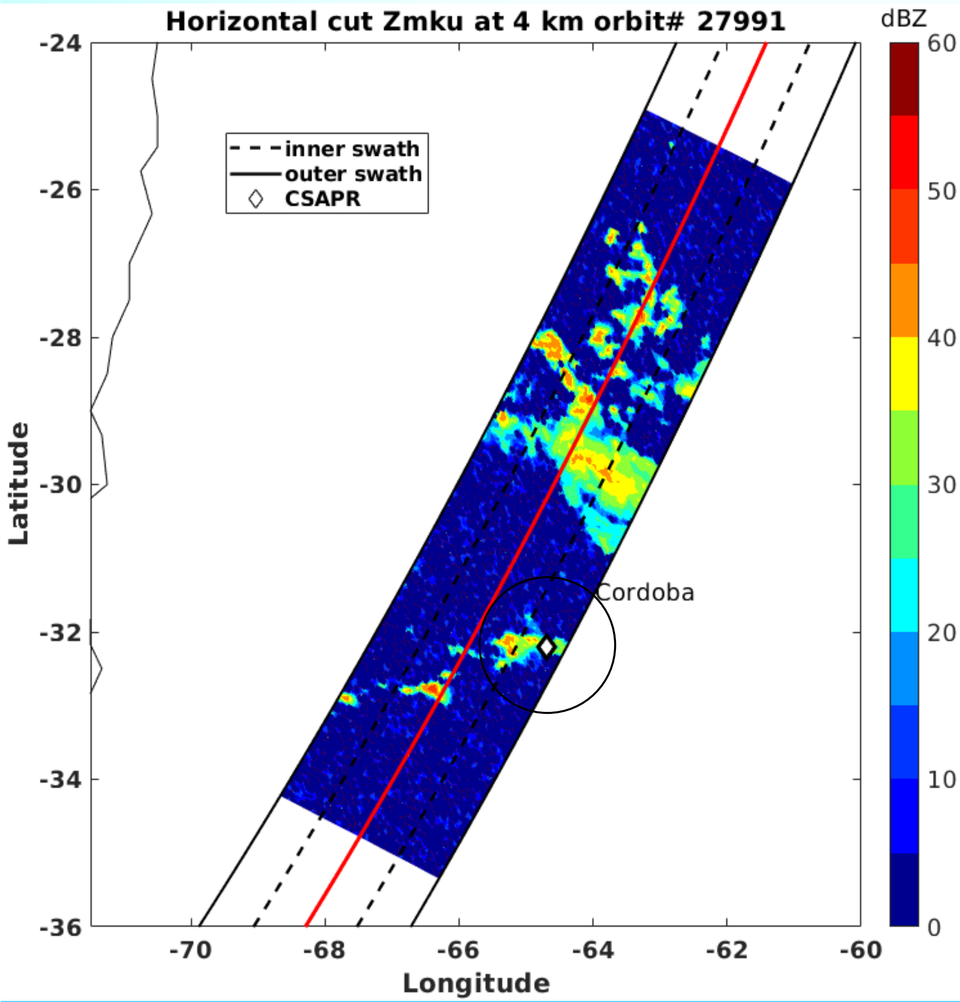
- **GPM orbit # 27991 on 2019/01/31, 22:35 UTC**
- **Campaign area**
  Latitude [-34.8 -25.4]
  Longitude [-71.4 -53.2]

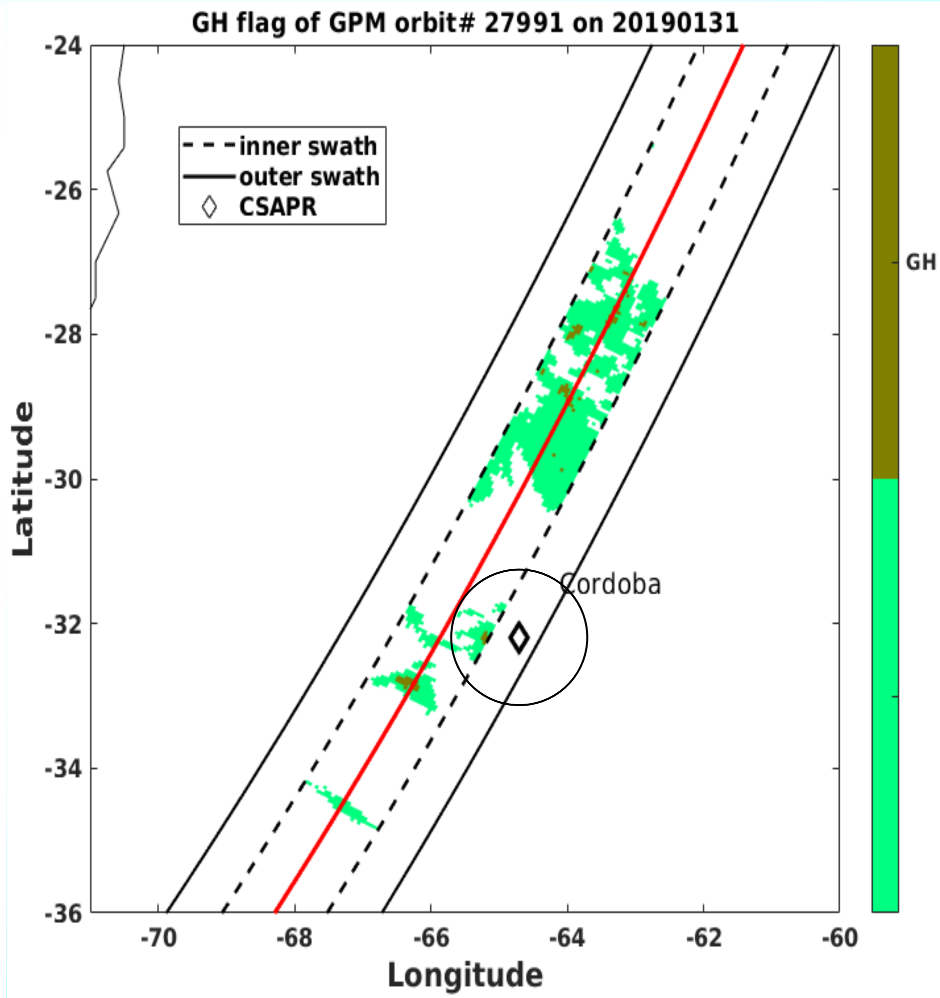


Validation during Relampago

Case detail: GPM orbit # 27991 on 2019/01/31, 22:35 UTC

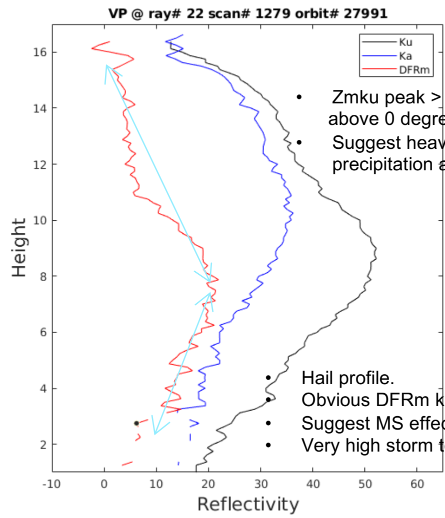
"flagGraupelHail" of the overpass





Case: GPM orbit # 27991 on 2019/01/31

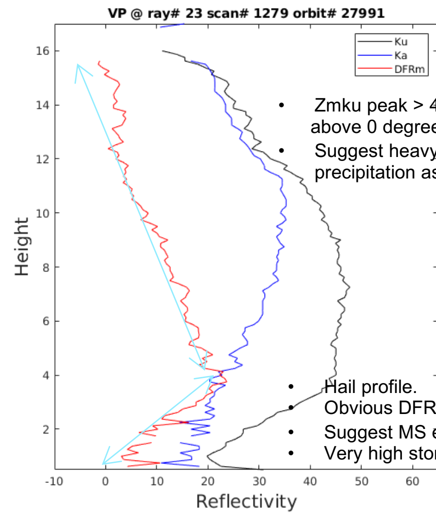
a



- Zmku peak > 40dBZ above 0 degree.
- Suggest heavy precipitation as hail

- Hail profile.
- Obvious DFRm knee.
- Suggest MS effect.
- Very high storm top.

b



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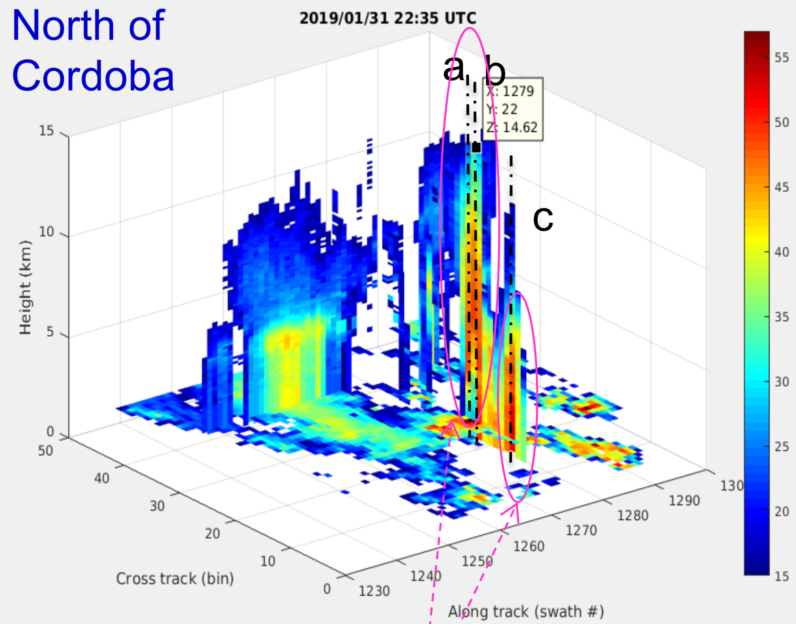
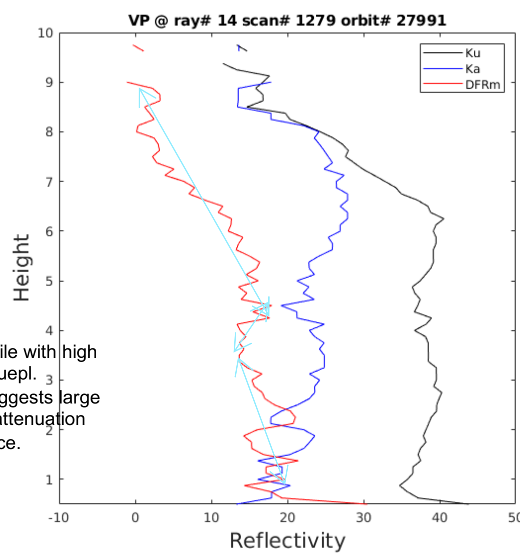
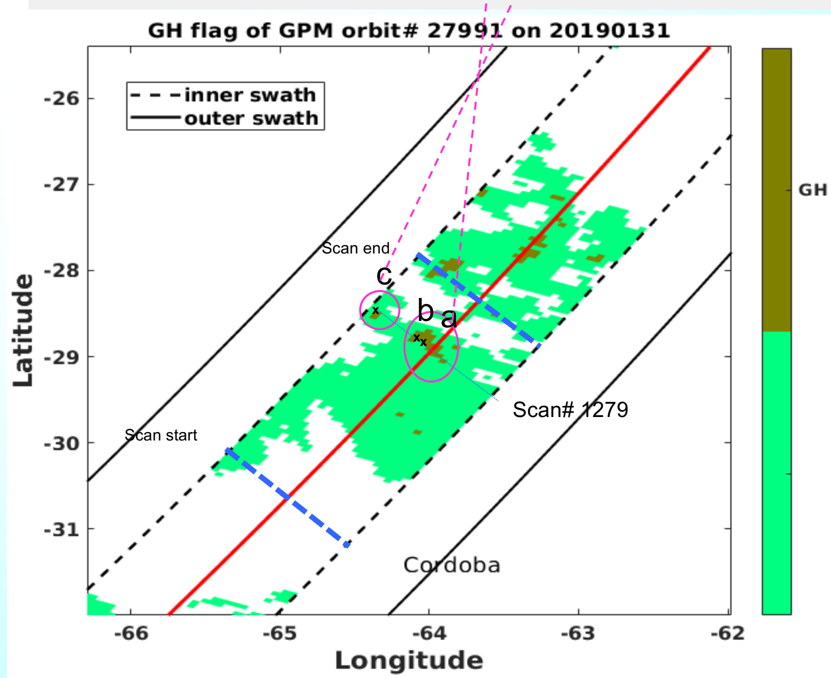
North of Cordoba



c



- Typical Convective profile with high density particles as grauepl.
- Large DFRm value suggests large particle size and large attenuation difference toward surface.
- No MS effect.
- Very high storm top.

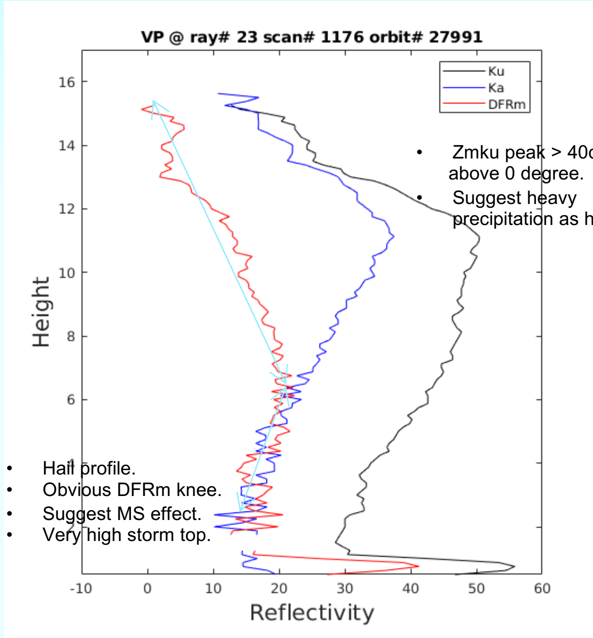


Case:

GPM orbit # 27991 on 2019/01/31

South of Cordoba

a



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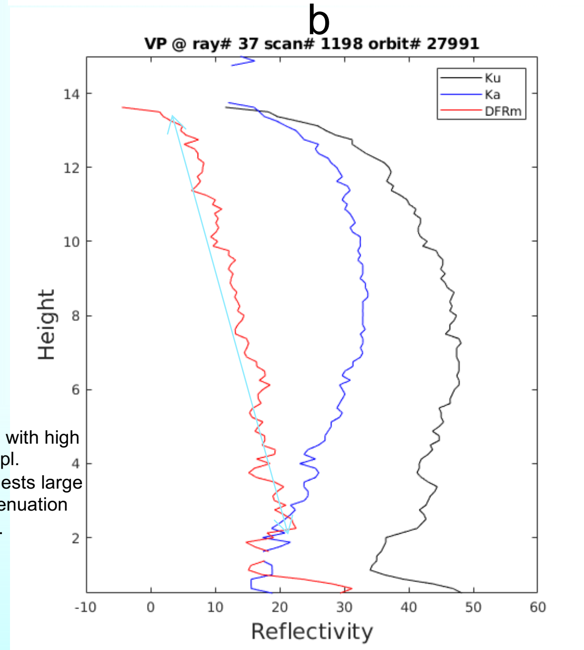

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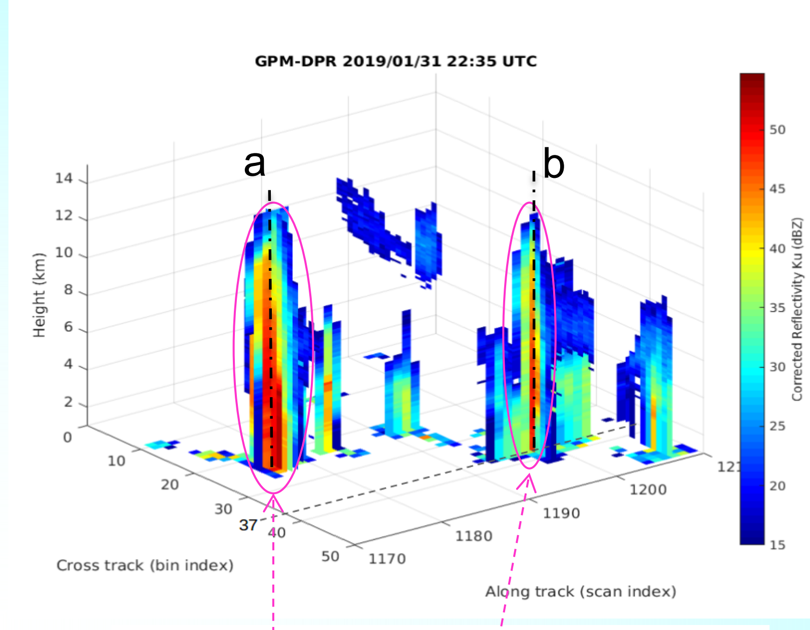
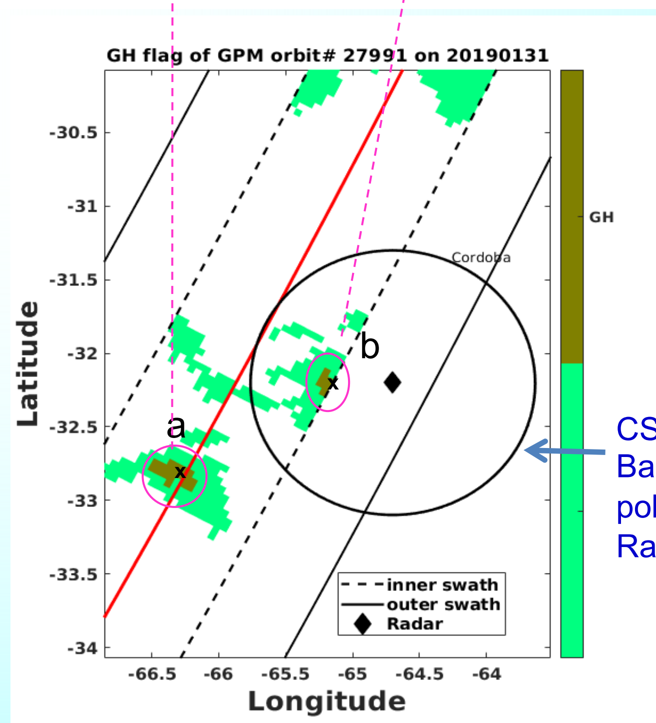
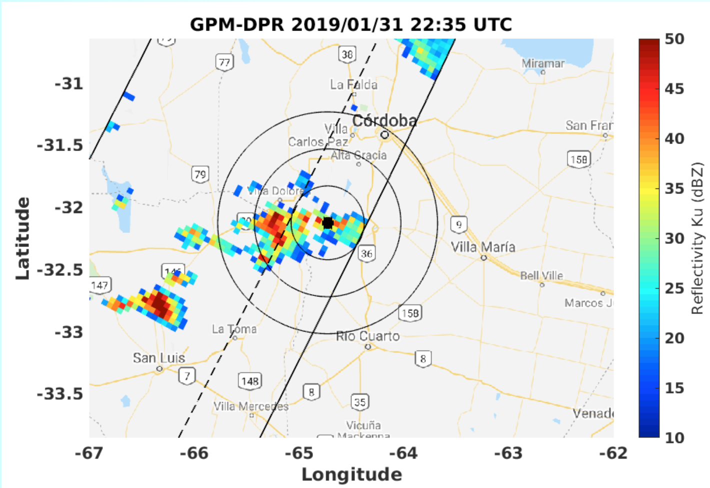




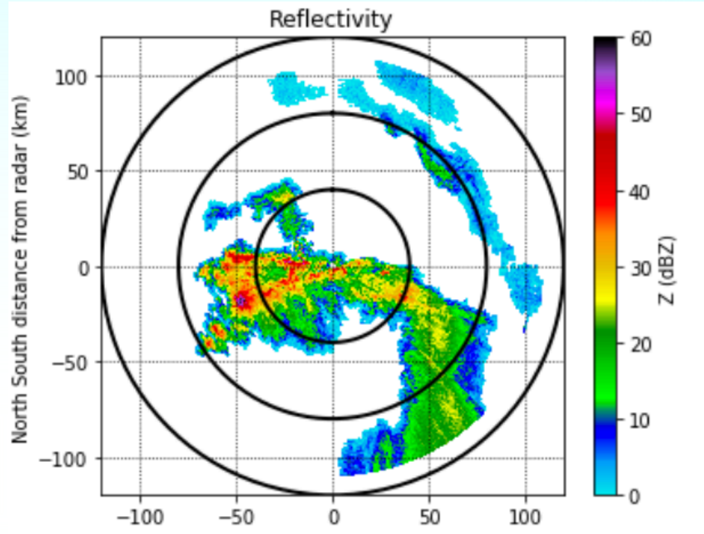
CSAPR: C-Band Dual-polarization Radar

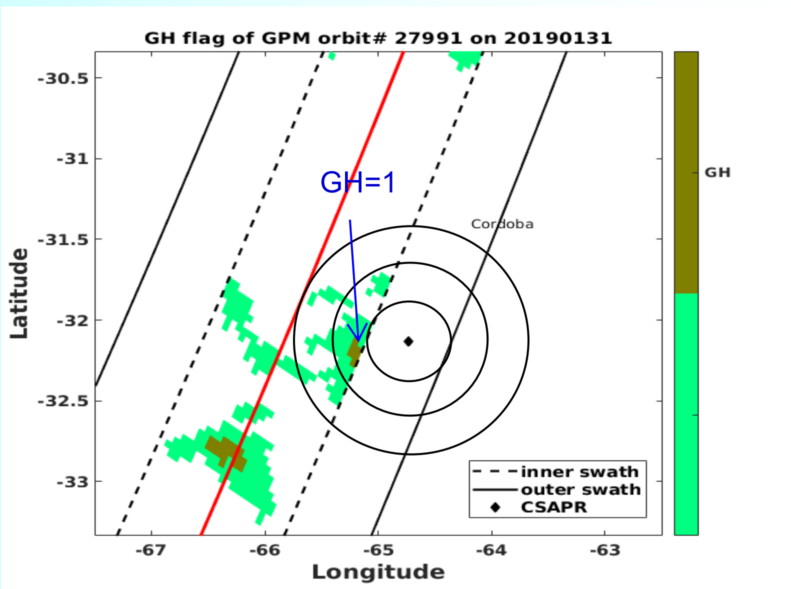
Case: GPM orbit # 27991 on 2019/01/31
Compare with CSAPR2 radar

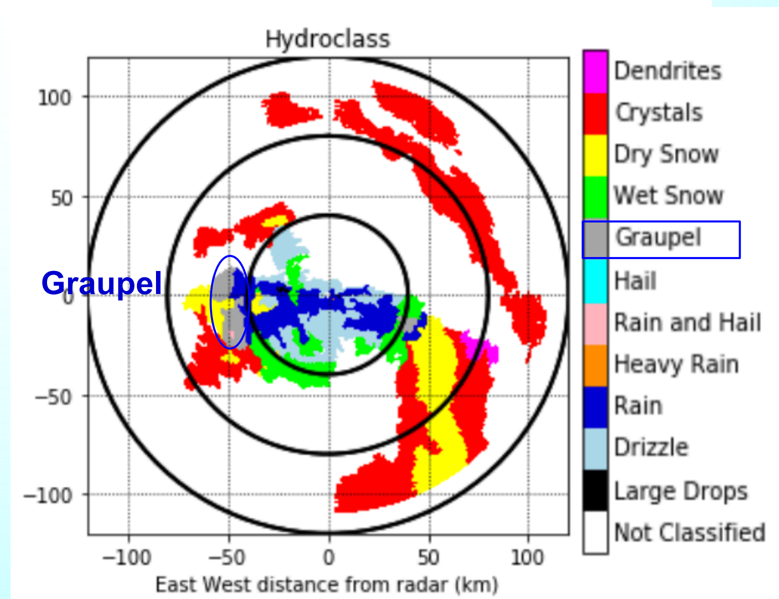
CSAPR: C-Band Dual-polarization Radar



CSAPR-radar Elevation 3.7 degree.
2019/01/31/22:32 UTC

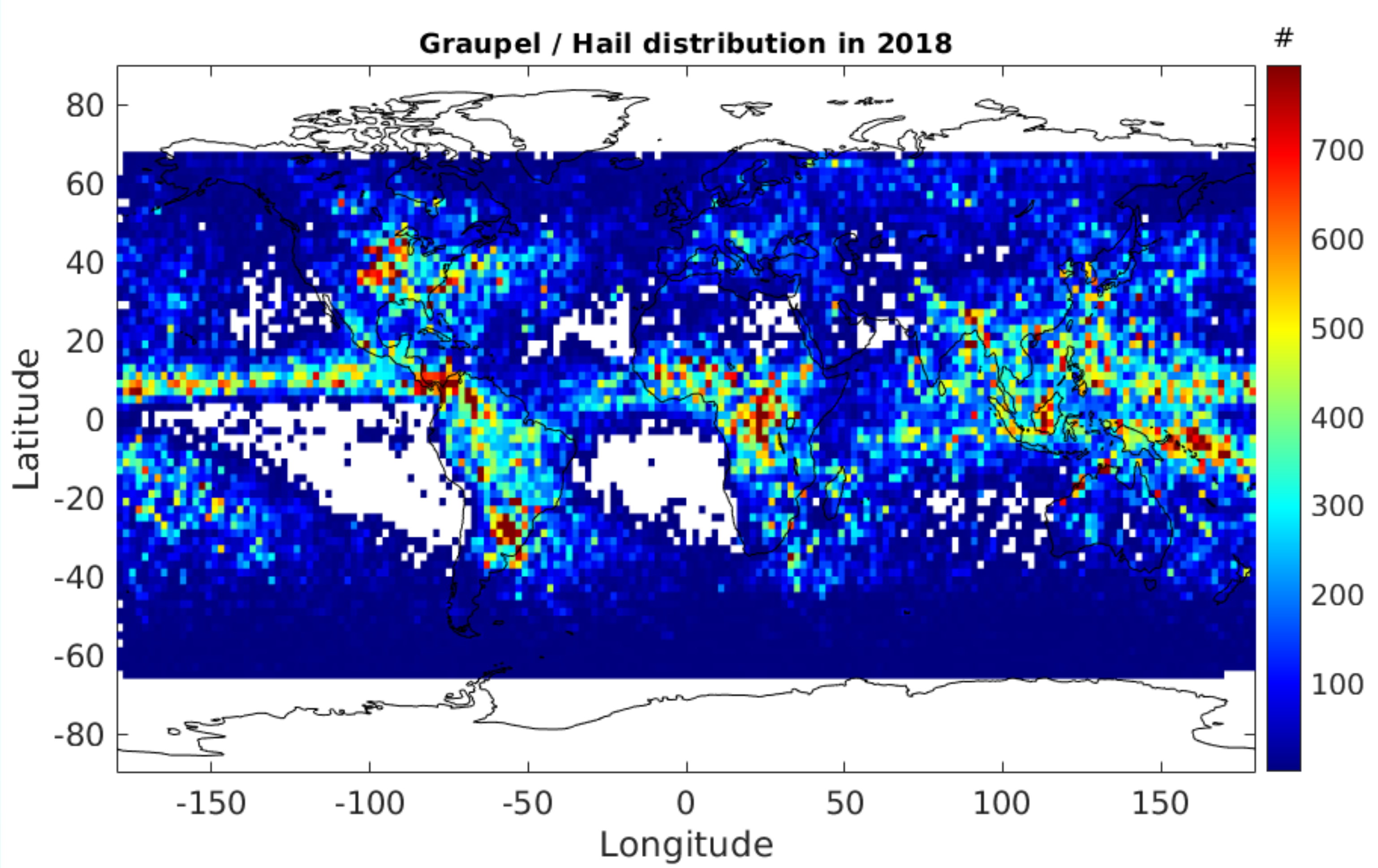




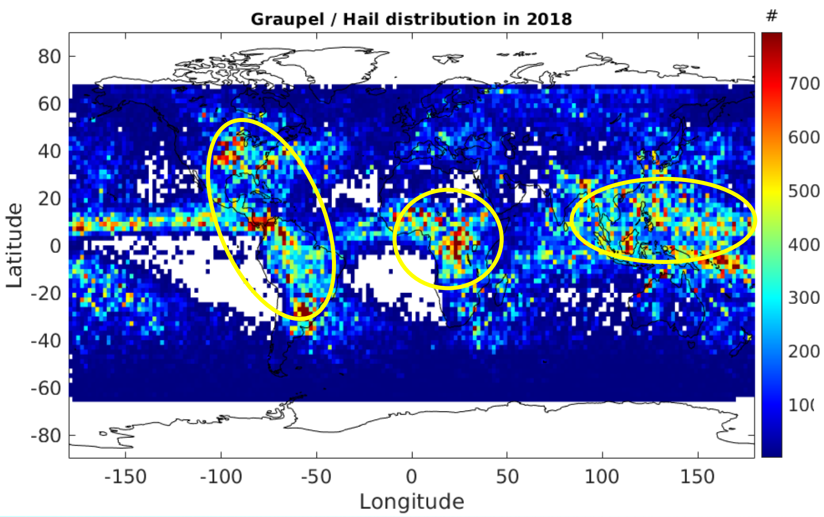


Global Scale Analysis

Global distribution of "flagGraupelHail" count mapping to the 2° x 2° Lat / Lon box for year 2018.



Global Scale Analysis



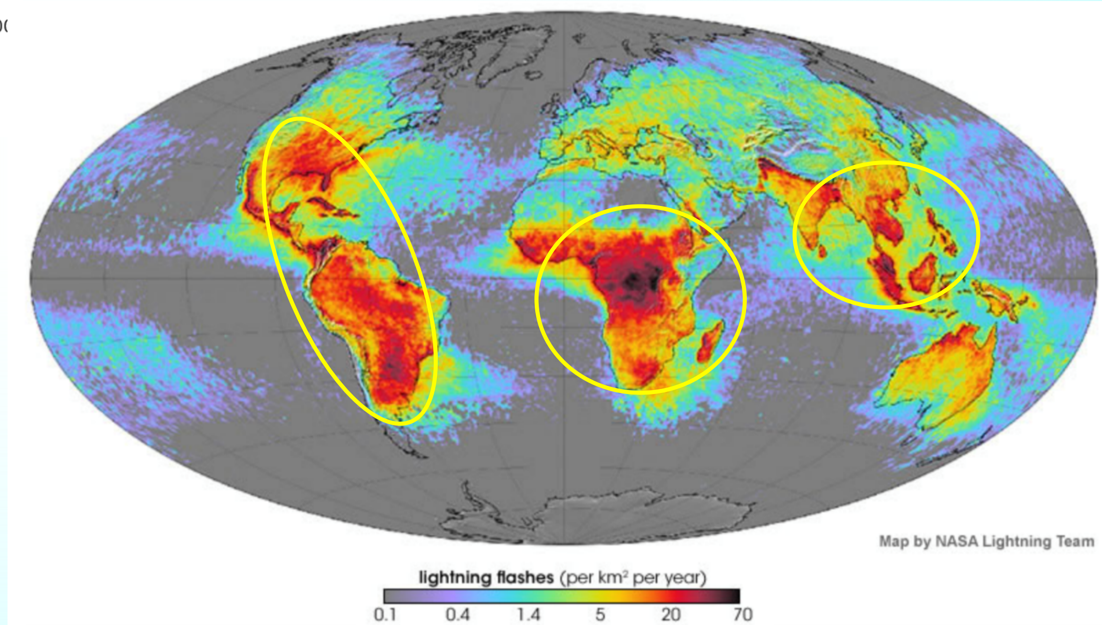
Global distribution of “flagGraupelHail” count mapping to the 2° x 2° Lat / Lon box for year 2018.

- active lightning regions are believed to be associated with the existence of graupel at high altitudes.
- Good association can be found at circled areas between these two maps.

- More lightning occurs over land than over the ocean.
- More lightning occurs near the equator than at the poles.

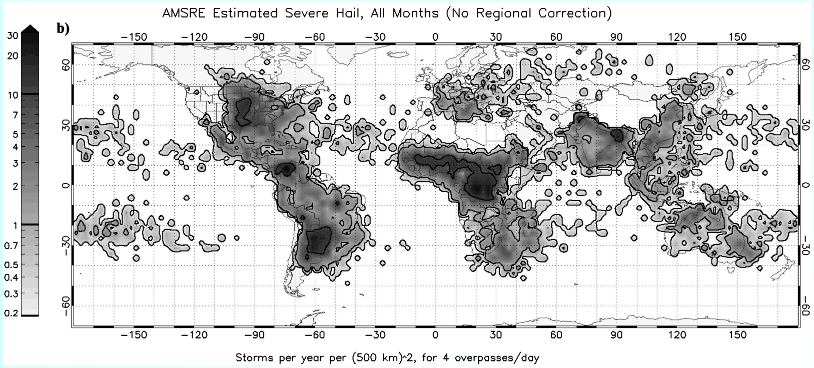
- Regions of Intense Lightning Activity:

The Democratic Republic of the Congo
Northwestern South America
The Himalayan Forelands
Central Florida
The Pampas of Argentina
Indonesia

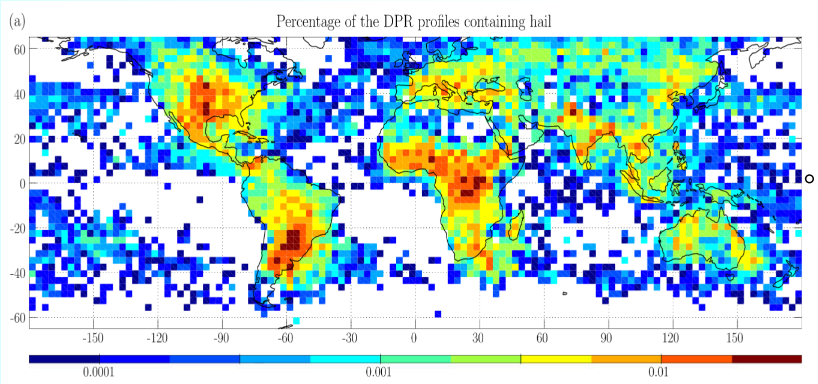


World Lightning Map: The map above shows the average yearly counts of lightning flashes per square kilometer based on data collected by NASA's Lightning Imaging Sensor on the Tropical Rainfall Measuring Mission satellite between 1995 and 2002. Places where less than one flash occurred (on average) each year are gray or light purple. The places with the largest number of lightning strikes are deep red, grading to black. (This Map is made by NASA Lighting Team).

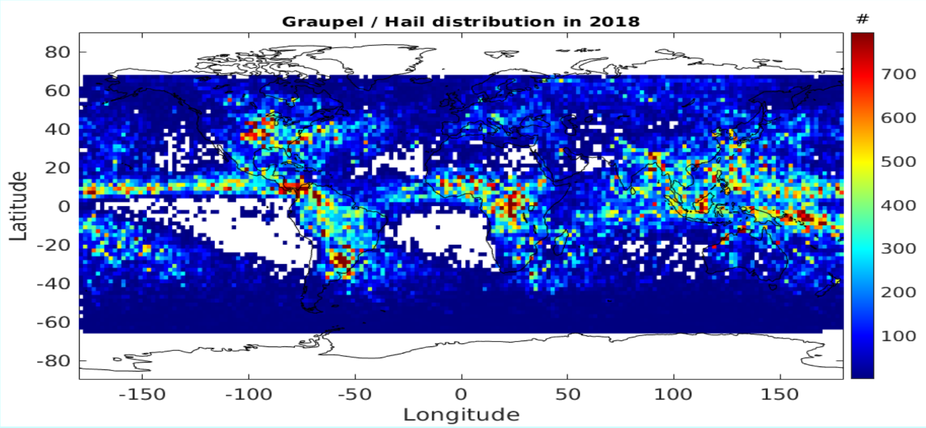
Global Scale Analysis



- Hailstorm frequency of occurrence estimated from Advanced Microwave Scanning Radiometer for Earth Observing System (AMSR-E), 36-GHz polarization-corrected temperature (PCT) , from 2003–2010. Units are storms per 500 kilometers squared per year, using 2.5° grid spacing and bilinear interpolation (Cecil and Blankenship2012).

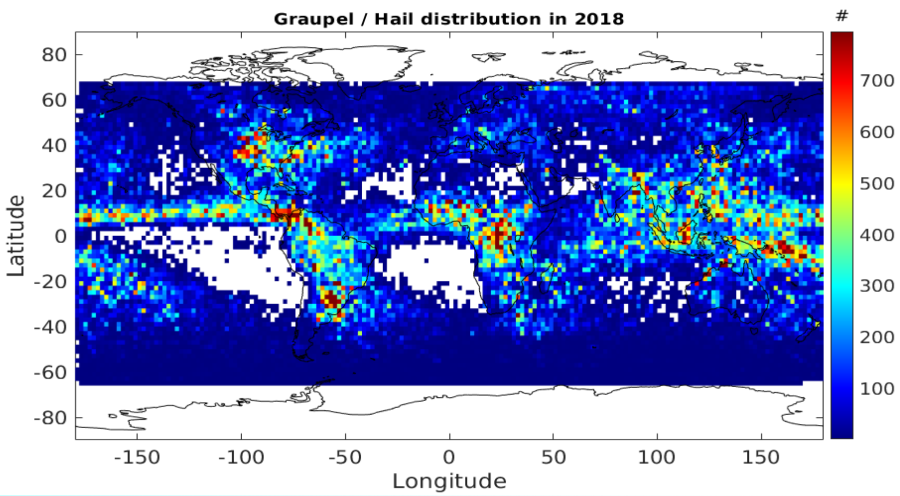


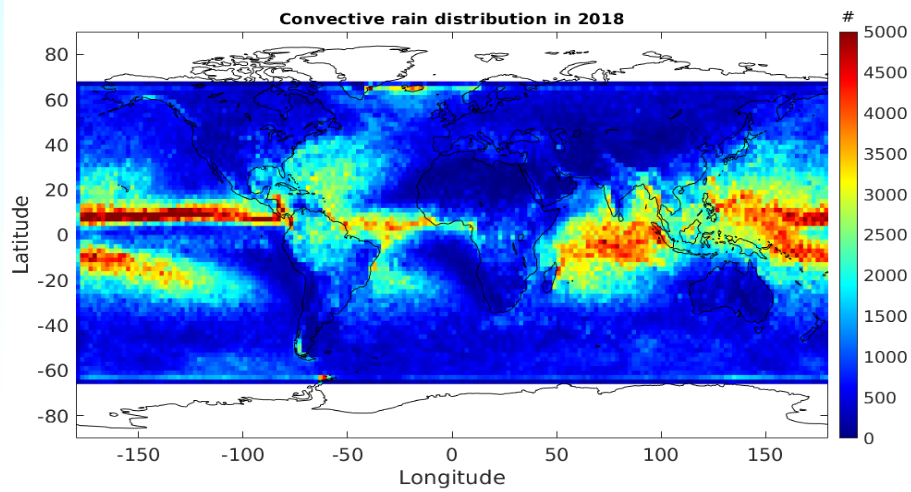
- Global map of the fraction of the DPR profiles that contain hail based on combined method of radar and radiometer of GPM from year 2014 to 2016 using 3° grid. The parameters used are the Zku_mix and PCT at 36.6 and 10.7 GHz from GMI. (Mroz et al, 2017)



- The spatial patterns of DPR profile counts with hail and graupel are generally consistent with satellite-based estimates from radiometer or combined.
- Peaks of occurrence are at e.g., equatorial Africa, the equatorial and subtropical Americas, the Pampas of Argentina, the Himalayan Forelands, Indonesia.
- Bottom is for Graupel and Hail, and above two plots are for hail only.

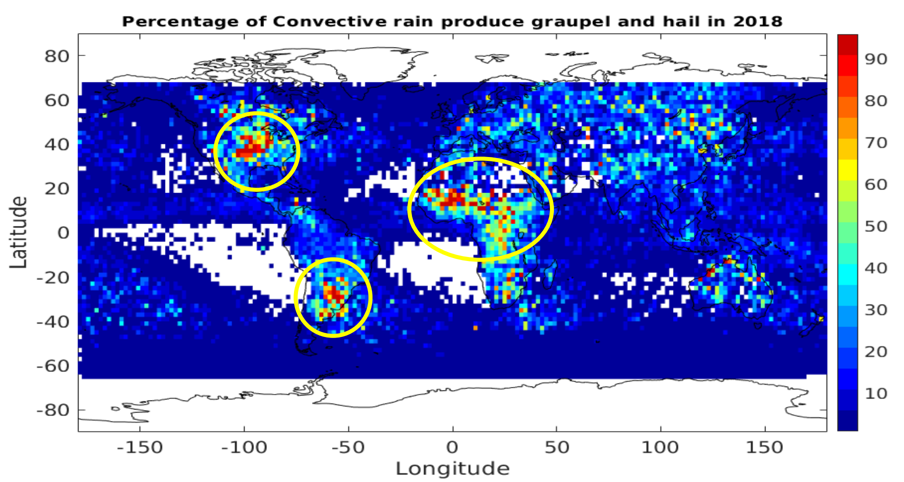
Global Scale Analysis





- Global distribution of "flagGraupelHail" count mapping to the 2° x 2° Lat / Lon box for year 2018.

- The global distribution of Convective rain count mapping to the 2° x 2° Lat / Lon box for year 2018.

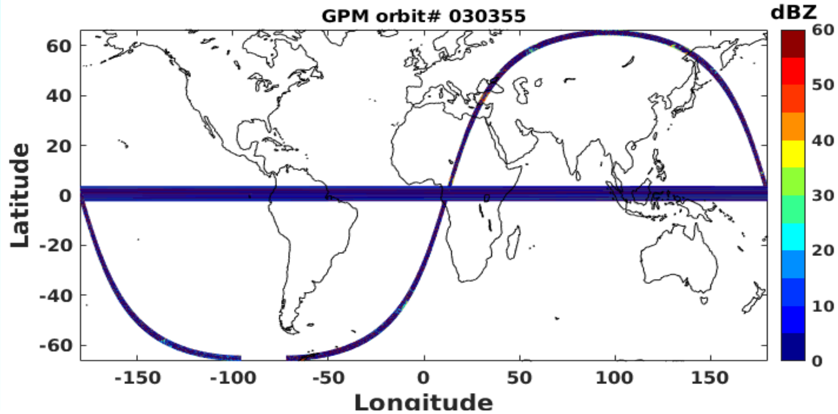


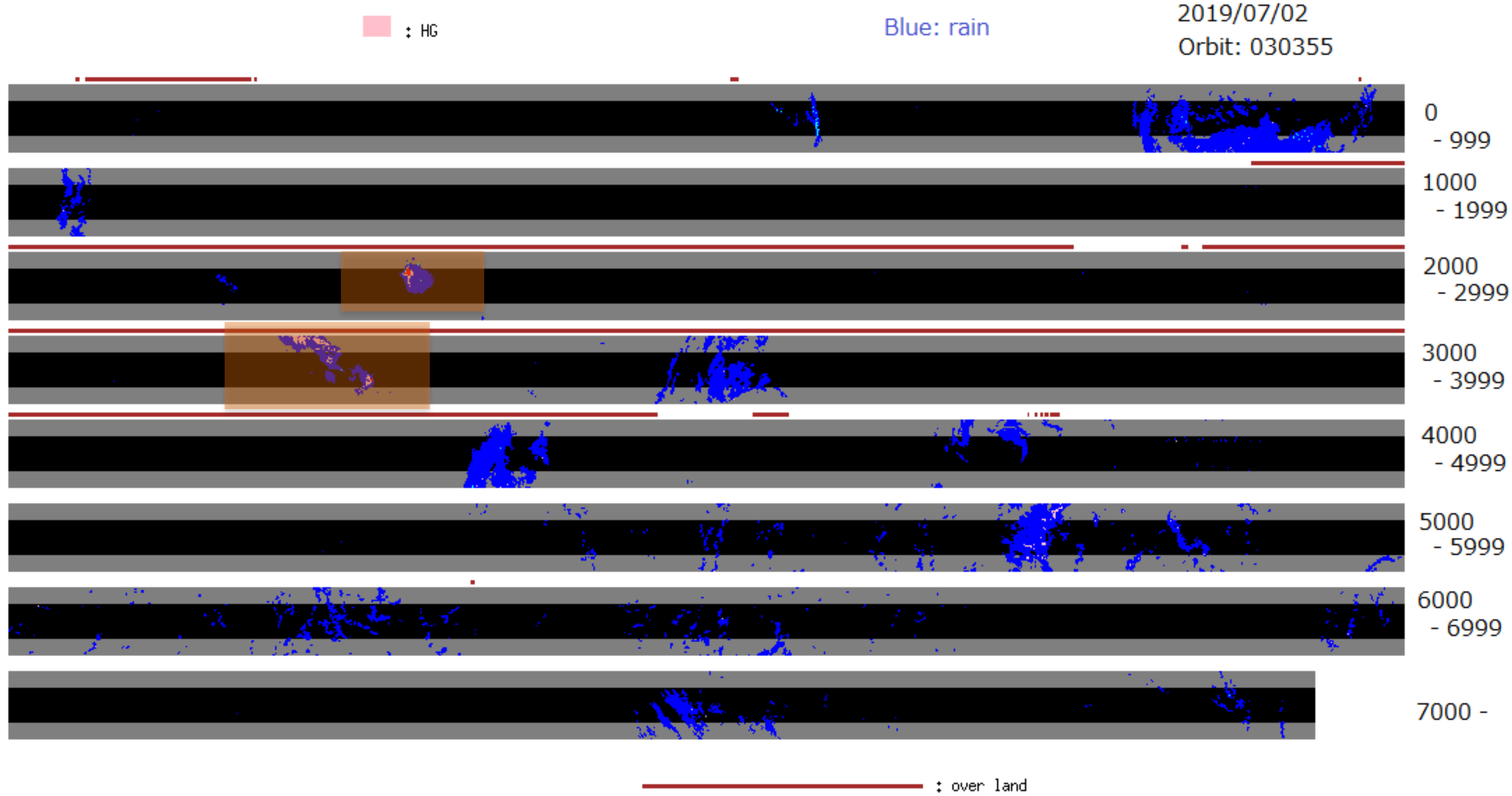
- Percentage of Convective rain that has graupel and hail in 2018.

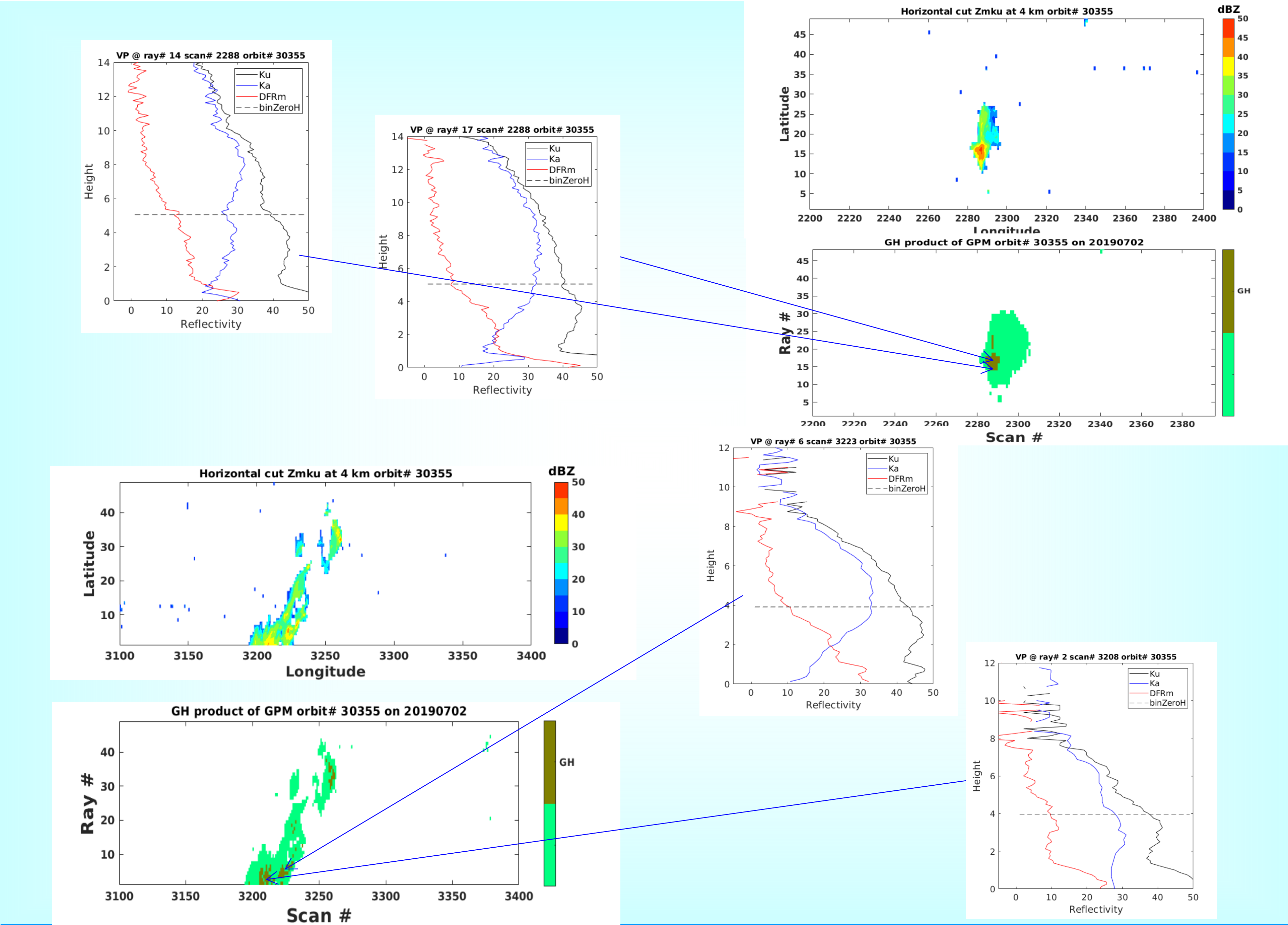
The highest % of convective rain that is caused by Graupel and Hail is located at:

- Southeast of North America
- La Plata basin in South America
- Central Africa

Initial Implementation of the Algorithm







VP @ ray# 14 scan# 2288 orbit# 30355
VP @ ray# 17 scan# 2288 orbit# 30355
Horizontal cut Zmku at 4 km orbit# 30355
GH product of GPM orbit# 30355 on 20190702
VP @ ray# 6 scan# 3223 orbit# 30355
Horizontal cut Zmku at 4 km orbit# 30355
GH product of GPM orbit# 30355 on 20190702
VP @ ray# 2 scan# 3208 orbit# 30355
Ku
Ka
DFRm
binZeroH
Height
Reflectivity
Latitude
Longitude
Ray #
Scan #
dBZ
GH

Summary and Conclusion

- The flag of “flagGraupelHail” has been implemented in the Experiment module of version V06X in GPM DPR level-2 algorithm.
- This product is built upon vertical features of DPR observations. A precipitation type index (PTI) is found to be effective in detection and separation of Graupel & Hail profiles.
- Validation of the algorithms include with WSR-88D radar network and CSAPR radar during Relampago Campaign. The results show great performance of the algorithm. More quantitative analysis will be performed in near future.
- Global distribution for the product of “flagGraupelHail” shows nice association with the global lighting map as well as estimations from passive instruments.

THANK YOU